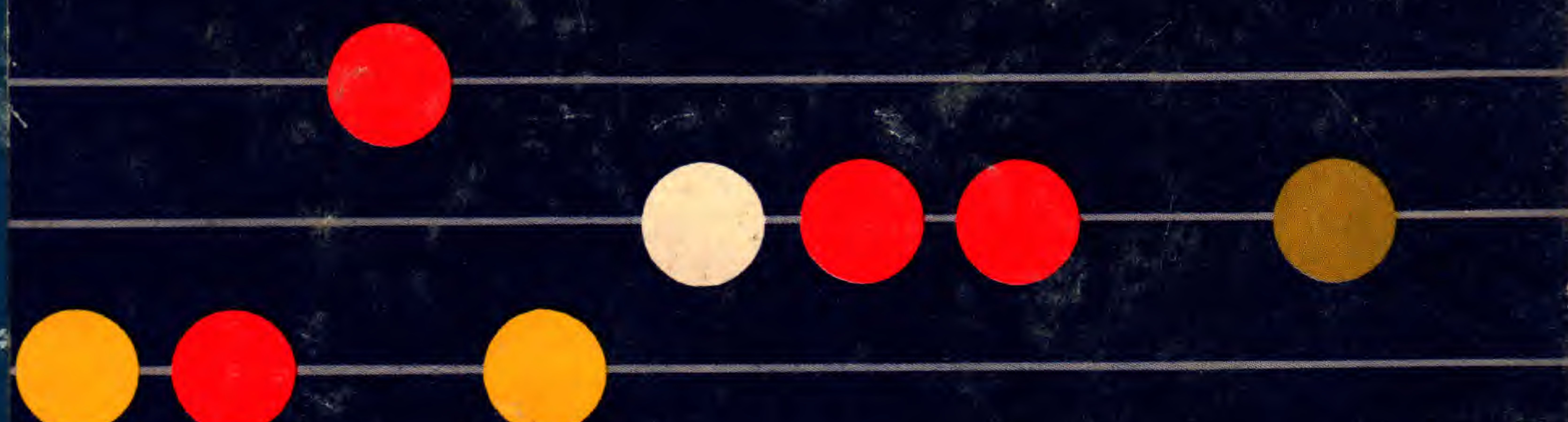
I CAN LEARN ABOUT CALCULATORS AND COMPUTERS



Raymond G. Kenyon

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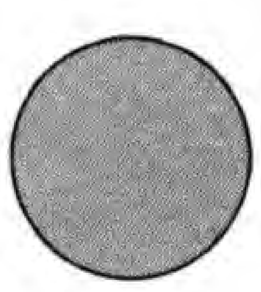

WITH DRAWINGS BY THE AUTHOR

Calculators and Computers

RAYMOND G. KENYON

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To KATHLEEN and COLLEEN
and the "new generation"

Thank You

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To International Business Machines Corporation, 590 Madison Avenue, New York 22, New York

For reference manuals, educational publications, and information about numbers, calculators, and computers.

Contents

Introduction

This book was written to help you learn about calculators and computers. If you want to understand the large complex electronic machines used today, it will help you to read about and experiment with the earliest number systems and calculating devices. Therefore, the first section of this book contains a brief history of numbers, calculators, and computers. Then you will learn how a modern computer works. Next are simple instructions for several calculators and computers you can build yourself. Each one of these devices is a part of the history of this science and mathematics.

At the end of the book is a list of some of the terms used by the computer scientist so that you can better understand the language of this field. And lastly, there are listed several places where you can obtain further materials to continue your experiments with calculators and computers.

I Can Learn About Calculators and Computers

How Early Man Counted and Computed

In the beginning, man counted on his fingers. With his fingers he showed others how many bison he had killed while hunting, how many people lived in his community, or how many berries he had picked. Thus he used his fingers to show quantity. At first only the five fingers on one hand were used. This led him to count by fives. As time passed man found it more convenient to use both hands and count by tens.

Today we refer to numerals and numbers as digits. The word "digits" comes from the Latin word *digiti,* meaning fingers.

Although primitive man could count and show how many

through the use of his fingers he still needed a way to record this information for future use. At first he recorded quantity by scratching notations on stones and cutting notches in sticks. Each scratch represented one bison, one person, or one berry. Next he recorded quantities he wanted to remember by using vertebrae and bones of animals, fish, and birds strung in bead form. Each bead was a symbol for a unit of one.

Probably the first written expression of quantity was picture symbols painted on the walls of caves. A painting of one bison represented one bison killed. This was a long and difficult process, and early man soon realized that special written symbols could be used to represent quantities of more than one. For instance, one symbol could be used to show two bison killed, another three bison killed, etc. Man no longer had to draw two bison to show the number two. He simply used a symbol that represented two. The use of special symbols to represent quantity was the beginning of a written number language.

Sometime around 3400 B.C. the early Egyptians decided they needed a series of number symbols that could be understood by those with whom they traded. To achieve this end, they devised a system of number symbols from one up to hundreds of thousands in figures called hieroglyphics. Figure 12 shows the Egyptian hieroglyphics for the numbers one through ten. These particular symbols probably were

used in imitation of the raised fingers of the hands when counting.

The Egyptians also invented a sand calculator with which to do complex problems. They made columns of grooves in the sand, the right-hand groove representing the ones column, the next groove to the left representing the tens column, the third groove to the left representing the hundreds column, etc. (See Figure 1.) Pebbles or small stones were placed in these columns to form a simple calculator. The number value of each pebble grew as it was moved from

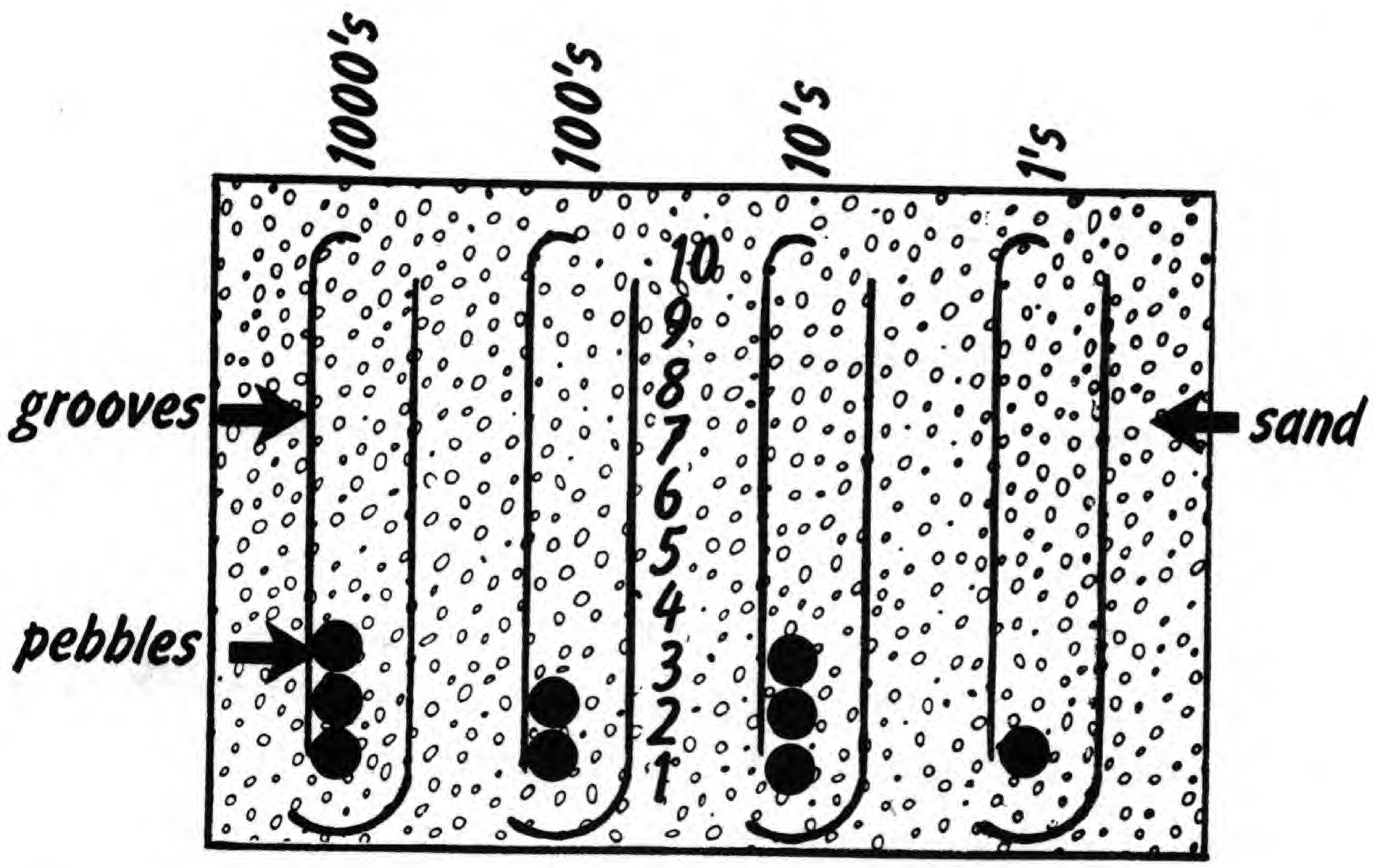


Fig. 1. Egyptian sand abacus.

groove to groove. In the right-hand column each pebble was worth 1. In the next column to the left each pebble was worth 10×1. In the third column to the left each was worth $10 \times 10 \times 1$, and in the fourth column to the left each pebble was worth $10 \times 10 \times 10 \times 1$. Notice that the value of each pebble grew by 10 each time it was moved a column to the left. Today we refer to any system of counting or measurement based on ten as a decimal system. Historians believe that the Egyptians were the first to use such a system.

At the same time the Egyptians were working on their number and calculating devices, another great civilization, Babylon, was developing a number system of its own based on wedge- or V-shaped symbols (see Fig. 12). The Babylonians did their calculations on wet clay rolled into tablets. A pointed wooden stick was used to engrave cuneiform (wedge-shaped) number symbols in the clay tablets while they were wet. Then the tablets were set out in the sun to bake. Some of these tablets can still be seen in museums, and the markings on them indicate that the Babylonians had worked out tables for the squares of numbers. (See Figs. 2 and 3.) The square of a number is the product of some smaller number multiplied by itself. For instance, 9 is said to be the *square* of 3 because $3 \times 3 = 9$. Instead of writing 3×3, modern mathematicians write 3^2. Since $3^2 = 9$, modern mathematicians write 9 as 3^2. In the same way, since 6×6 (or 6^2) equals 36, 36 is written as 6^2.

Their tables of the squares of numbers were not the only means the Babylonians had for calculating. They too used sand calculators. When the answer was found, it was transferred to the clay tablets. However, the Babylonians not only used the system of 10s as the Egyptians did; they also used a system based on 60. In this system each of the pebbles in the first groove still had the value of one, but each of the pebbles in the next groove to the left was worth 60×1,

	1	2	3	4	5	6
1	1	2	3	4	5	
2	2	4	6	8	10	12
3	3	6	9	12	15	18
4	4	8	12	16	20	24
5	5	10	15	20	25	30
6	6	12	18	24	30	36

Fig. 2. Table of the squares of numbers.

in the next groove to the left, $60 \times 60 \times 1$, and in the fourth groove, $60 \times 60 \times 60 \times 1$. But calculating with this system proved to be a long process. It meant the use of more pebbles and longer grooves in the sand to figure out the same problems that could be solved using the 10, or decimal, system.

However, the Babylonians' base of 60 is still used to some extent today. We use 60 seconds to represent one minute, and 60 minutes to represent one hour.

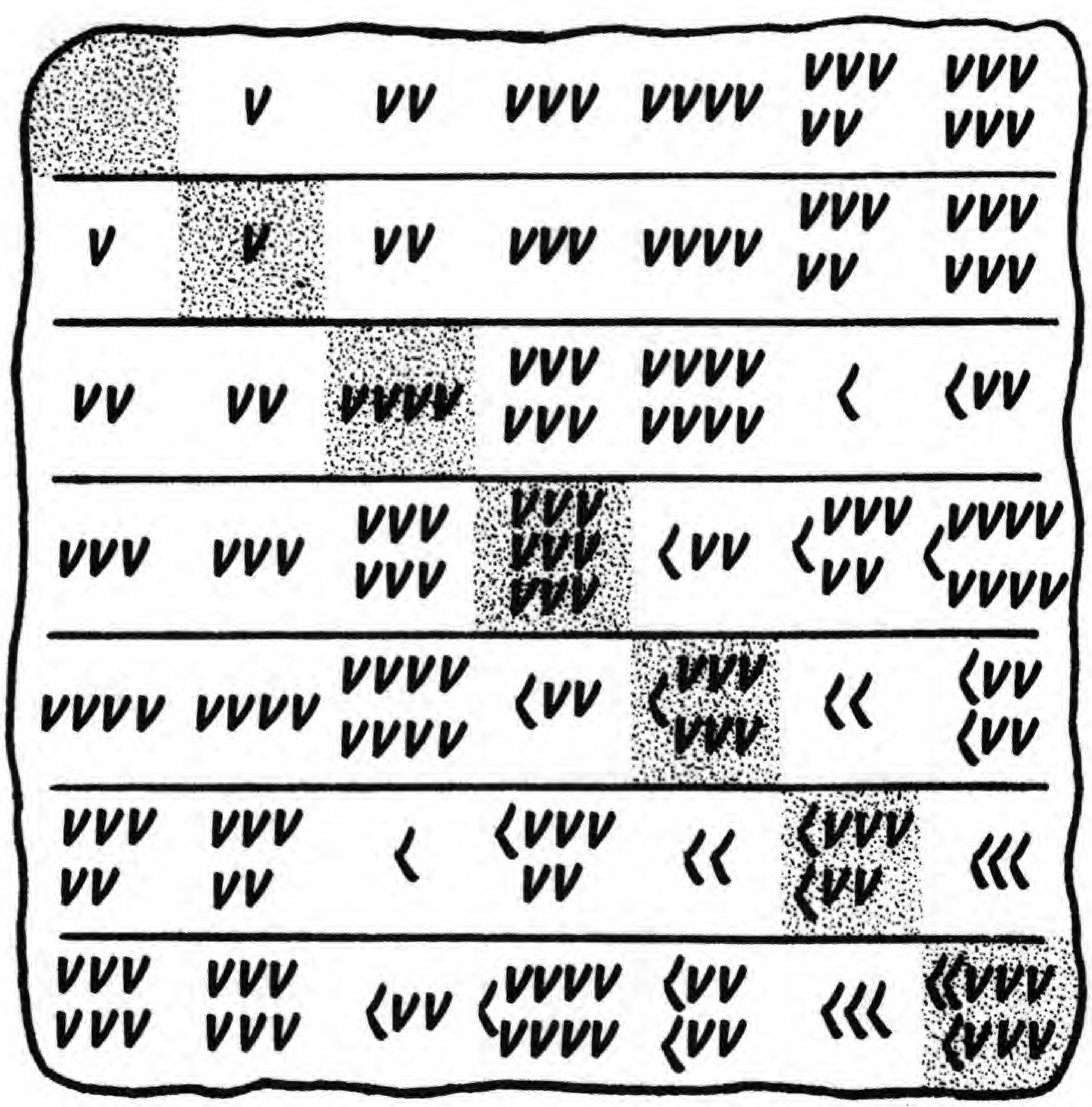


Fig. 3. Babylonian table of the squares of numbers.

The mathematicians and scientists of ancient Greece used characters from their alphabet as number symbols. At first they used the first letters of the words for the numbers. Later they used the first nine letters of their alphabet to represent the first nine numbers. To make it clear when a letter was being used to represent a number, they wrote a / or a ′ to the right of it.

In ancient Greece, the numbers from one to nine were written as follows:

GREEK NUMBERS:	A′	B′	Γ′	Δ′	E′	F′	Z′	H′	Θ′
OUR NUMBERS:	1	2	3	4	5	6	7	8	9

The next nine letters of the Greek alphabet were used to represent the tens from ten to ninety:

GREEK NUMBERS:	I′	K′	Λ′	M′	N′	Ξ′	O′	Π′	Q′
OUR NUMBERS:	10	20	30	40	50	60	70	80	90

And the last nine letters of the Greek alphabet stood for the hundreds from one hundred to nine hundred:

GREEK NUMBERS:	P′	Σ′	T′	Y′	Φ′	X′	Ψ′	Ω′	Z′
OUR NUMBERS:	100	200	300	400	500	600	700	800	900

A number was made a thousand times larger by placing a stroke in front of it. With this system large numbers could be expressed in less space than in previous number systems. As an example, 2610 in our number system would be ex-

pressed as /B′X′I′ in the ancient Greek number system.

Although the writing of large numbers in Greek was easier, calculations were more difficult. When an Egyptian used his sand abacus to write 2610, he simply put two pebbles in the thousands column, six pebbles in the hundreds column, one pebble in the tens column, and left the units column blank. The Greeks never developed a calculator that could use the / before a number to show thousands.

Instead of using counters or pebbles, such as the Egyptians did, the Greeks developed boards covered with a thin coat of wax and scratched their calculations on these boards. They removed the calculations when through by smoothing the wax with a spoon-shaped eraser. This waxed-board calculator was referred to as an *abax,* the Greek word for tablet, and historians have traced our word abacus back to it.

When the Romans conquered the lands surrounding the Mediterranean Sea, the use of Greek numbers gave way to the use of Roman numerals (see Figure 12). The Roman numerals we see today in chapter headings and on watches and clocks and public buildings were developed from the early Roman alphabet.

The one, two, three, and four of their number system were copied from the first four fingers of the hand (four was originally written as IIII instead of IV as later). Five, shown by the Roman numeral V, represented one hand. Two hands, or two V's, stood for ten, shown by the Roman

X (two V's tip to tip). *Centum* was the Roman word for 100, and *mille* the word for 1,000. C thus became the symbol for 100, and M for 1,000. The symbol D, for 500, is believed to have been taken from the right half of the Roman M (ɱ), the initial of *mille*. The L symbol for 50 was derived from the Greek symbol for this number, ν.

Calculating with this number system was slow and awkward. As the numbers grew larger, many more symbols were needed. If you multiplied 133 by 126 using Roman numerals, the problem would look like this!

						CXXXIII
						CXXVI
		C		XXX		III
	D		LLL		VVV	
M		CCC		XXX		
M		CCC		XXX		
MMMMMMMMMMMM		CCC				
MMMMMMMMMMMMMM	D	CCCCCCCCCC	LLL	XXXXXXXXX	VVV	III

						III
					V	
				XXXXXXXXXX		
			LLLLL			
		CCCCCCCCCCCC	L			
	DDD	CC				
MMMMMMMMMMMMMMMM	D					

MMMMMMMMMMMMMMMMDCCLVIII——Answer in Roman numerals

16,758——Answer in decimal numbers

Notice that it took twenty-four spaces to write the answer in Roman numerals and only five spaces to write it in decimal numbers.

In order to make such computations easier the Romans developed a counting table or abacus. They termed their calculator a counting table because the spheres or marbles they used were called counters. The table was constructed of bronze metal and consisted of two separate sets of parallel grooves. The longer grooves in the lower half of the abacus indicated the units, tens, hundreds, thousands, etc. The

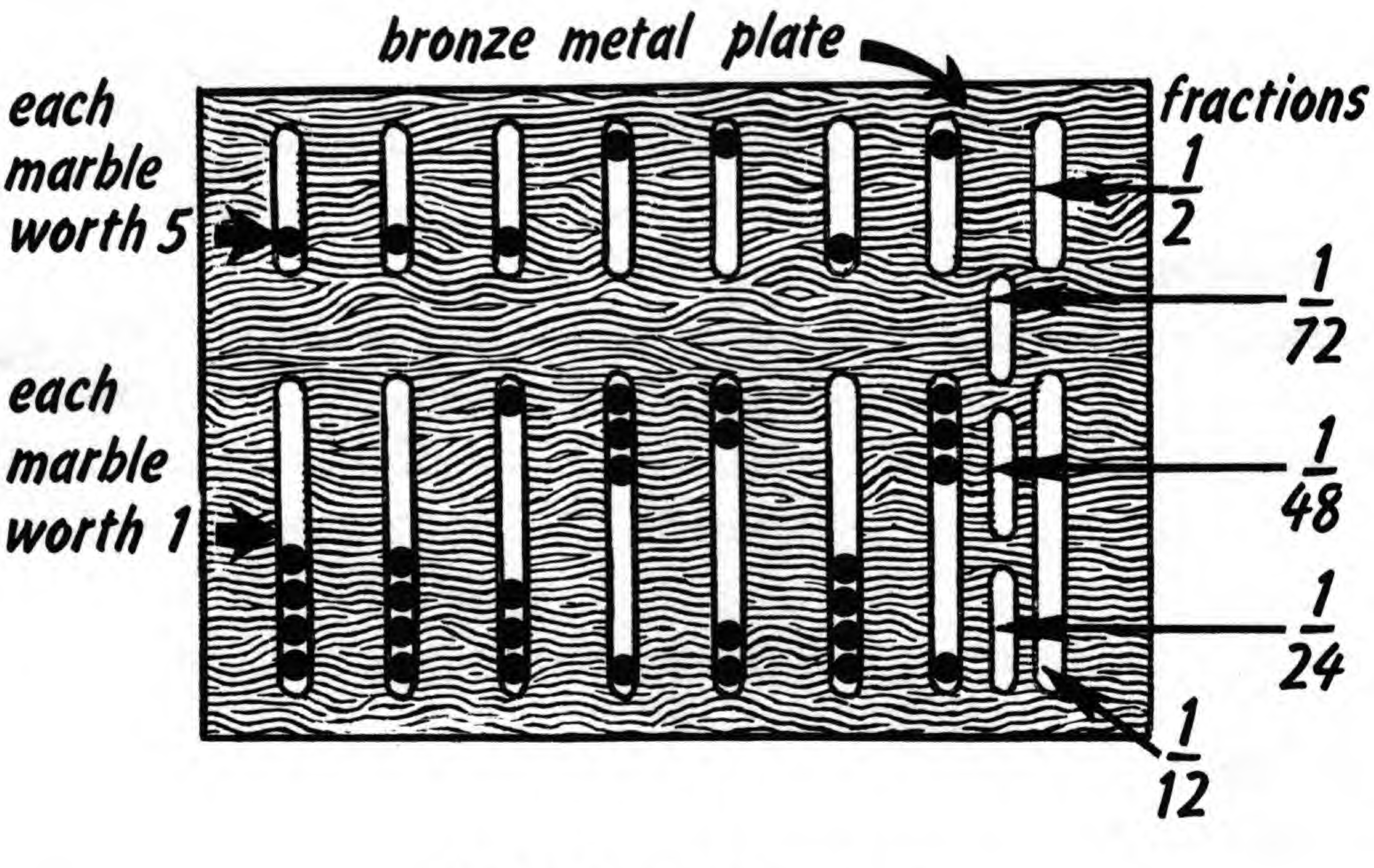


Fig. 4. Roman bronze abacus.

short upper grooves stood for fives, fifties, five hundreds, five thousands, etc. At the extreme right side of the abacus the Romans had columns to calculate fractions (see Fig. 4).

As in all abacuses, the marbles that were moved up from the bottom and down from the top were read, and the answer was found by reading along the middle of the abacus. (Other abacuses usually have a counting bar where the beads are moved to and read.)

The Chinese, too, developed a number system (Fig. 12), and by about 2800 B.C. they were using a written decimal system.

To calculate, the Chinese used counting rods. These rods were commonly made of bamboo split into three-inch lengths. One set of counters consisted of approximately 271 rods, which were kept in a bamboo case. The rods were placed in vertical positions, horizontal positions, and in combinations of both positions, as shown in Fig. 5, depending upon the number to be expressed.

Soon the idea of using rods for calculating spread to Korea, then to Japan. But this method of calculating proved to be slow and clumsy, and by 1384 it was replaced in China by the abacus. This invention consisted of rows of beads strung on thin bamboo dowels and set in a wooden frame, and it is still used today in many parts of the world.

In the abacus the right-hand column of beads stands for units or ones, the next left-hand column for tens, etc., up to millions (see Fig. 6).

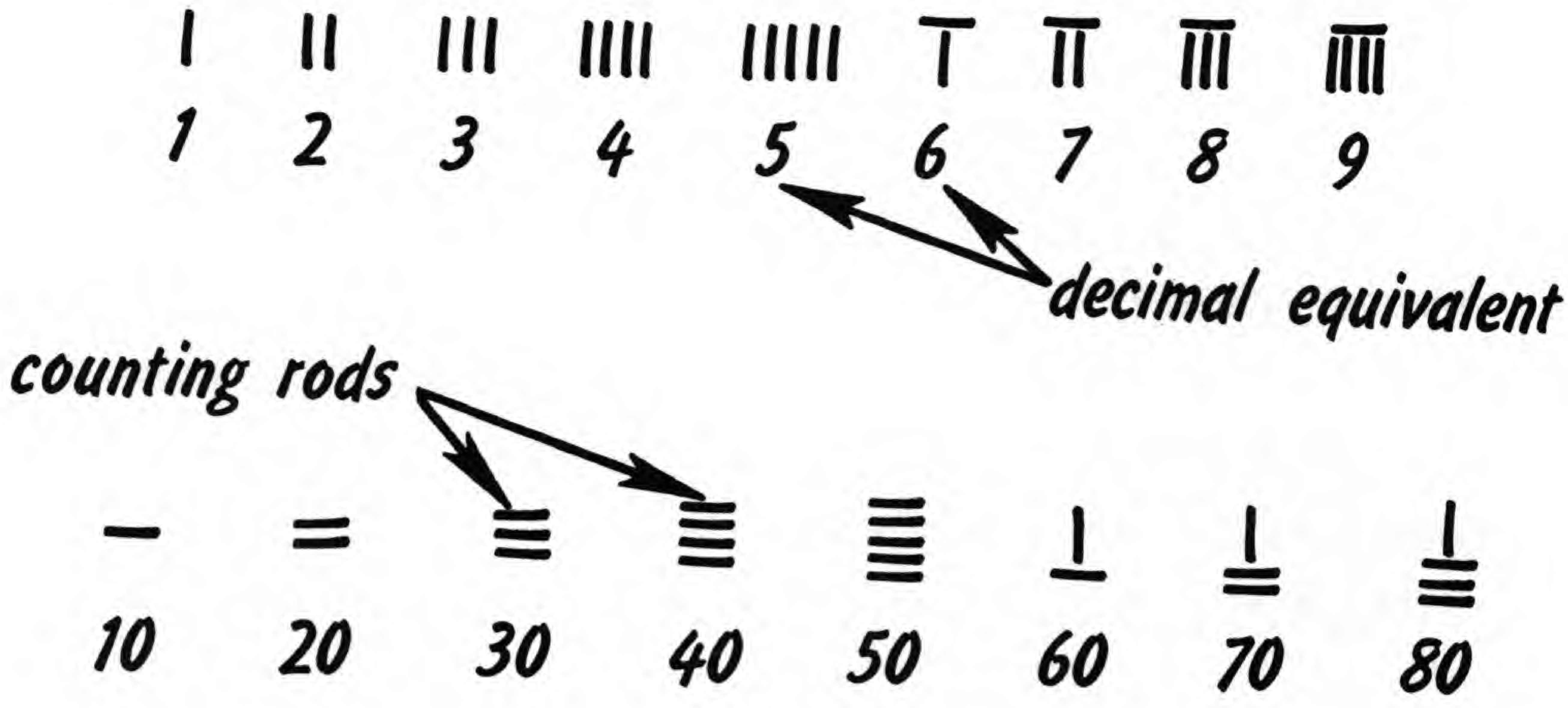


Fig. 5. Chinese method of representing numbers by means of computing rods.

By the year 1600 the Japanese were also using a form of abacus to do calculations (Fig. 7). It is believed that the idea for the Japanese abacus came from the Chinese, through Korea, to Japan. The Japanese abacus differs in two main ways from the Chinese version. First, sharp-edged buttons that could be easily moved by the fingers replaced the round-bead counters used by the Chinese. Second, instead of having two beads in the upper row, the Japanese abacus has only one button. The decimal value of the columns of buttons remained the same.

The Japanese and the Chinese abacuses can both be used to calculate complex problems quickly, but in both cases a great deal of the work involved is done mentally.

The Russians, the Turks, and the Armenians also devel-

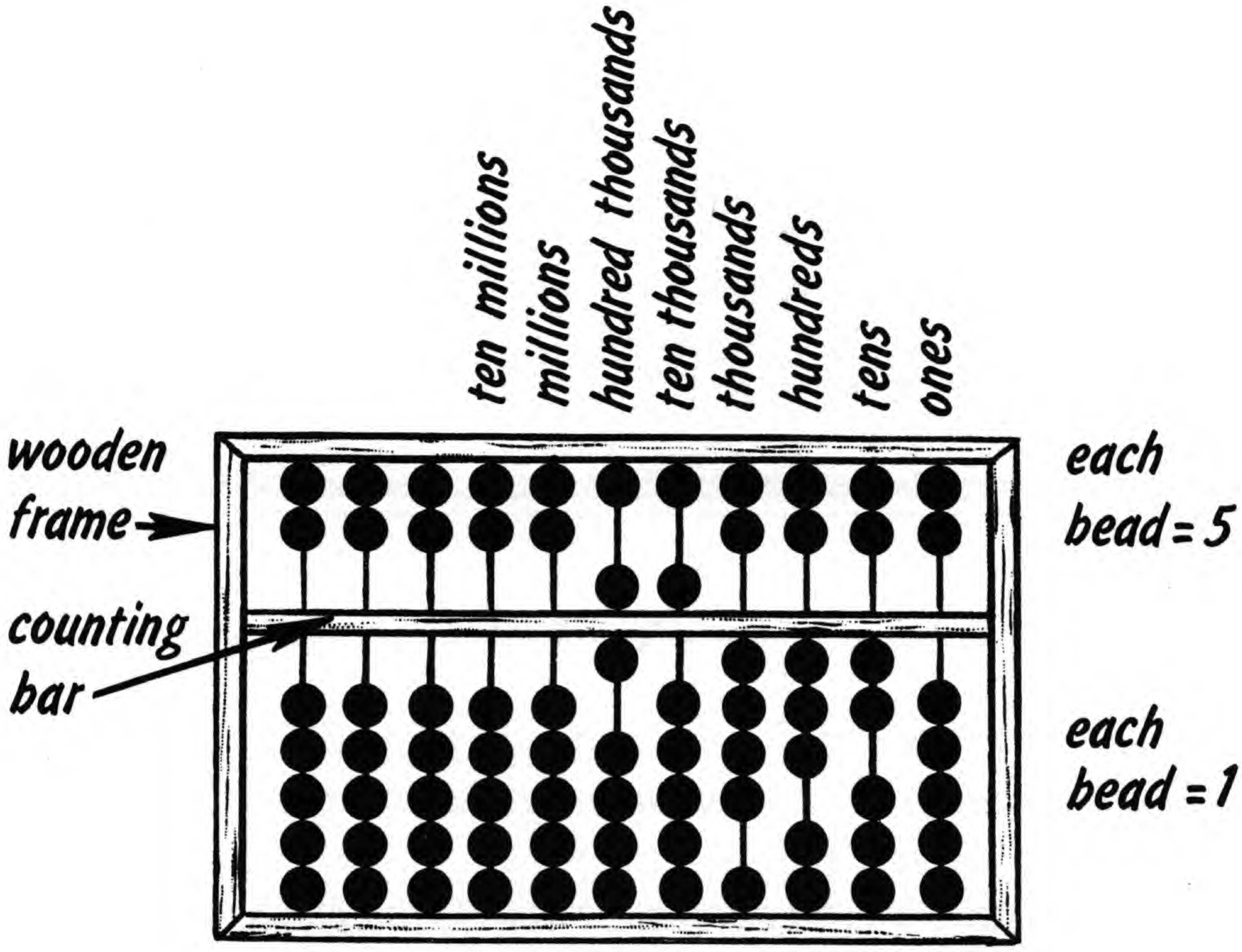


Fig. 6. Chinese abacus.

oped abacuses to use in making calculations. All these calculators were very similar to the one that was invented by the Chinese.

It is commonly believed that the number system used in our country today is of Hindu-Arabic origin (see Fig. 8).

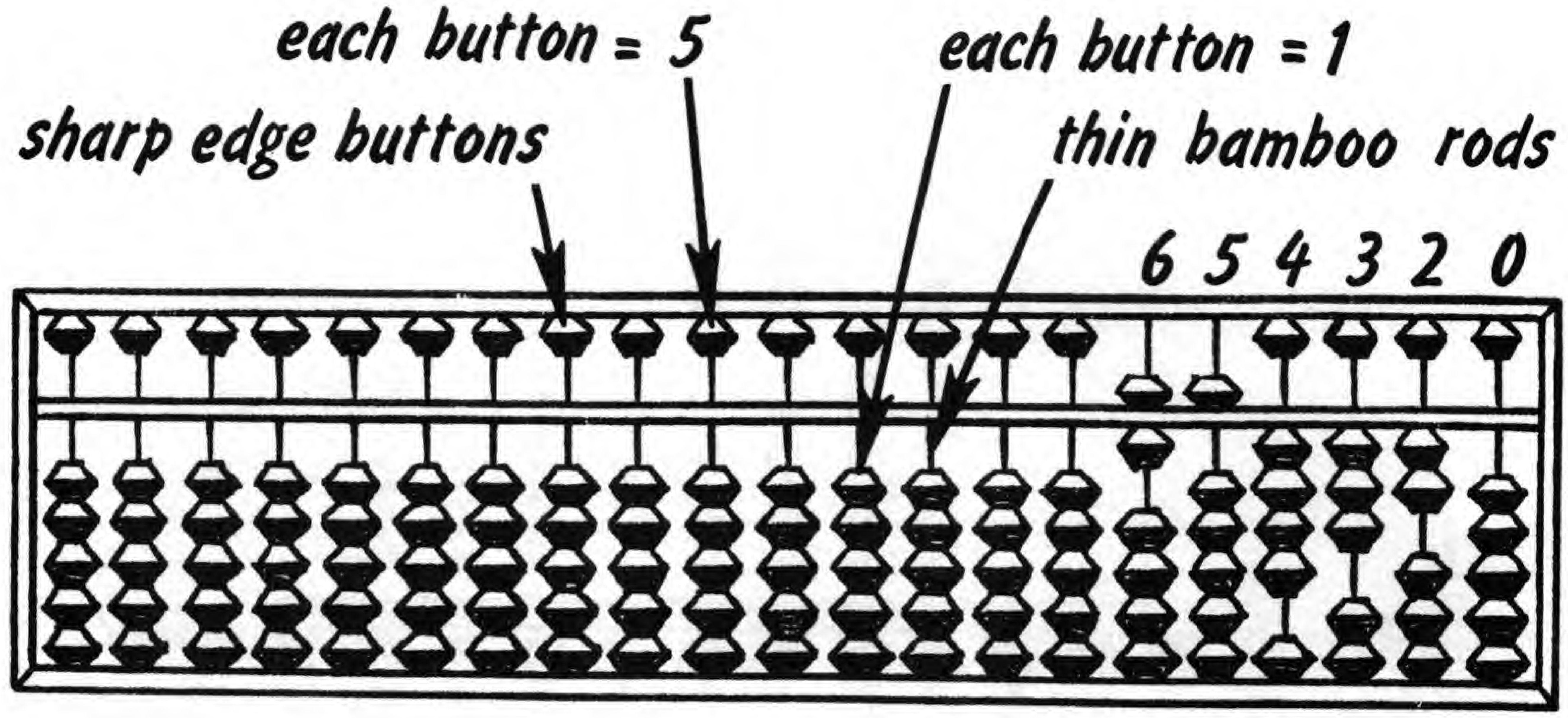


Fig. 7. Japanese abacus.

This system, it is thought, then spread to Spain, and from there throughout Europe.

The number symbols frequently changed shape as they were passed from one country to another (see Fig. 12). As different mathematicians copied the symbols by hand, each stressed various parts of each symbol according to his own handwriting.

When the Hindus calculated problems they used a small white tablet covered with red flour or dust and drew numerals on the tablet with a small sharp stick. These symbols became known as Sanskrit.

Another material used by the early Hindus for their calculations was the blackboard. The characters were written

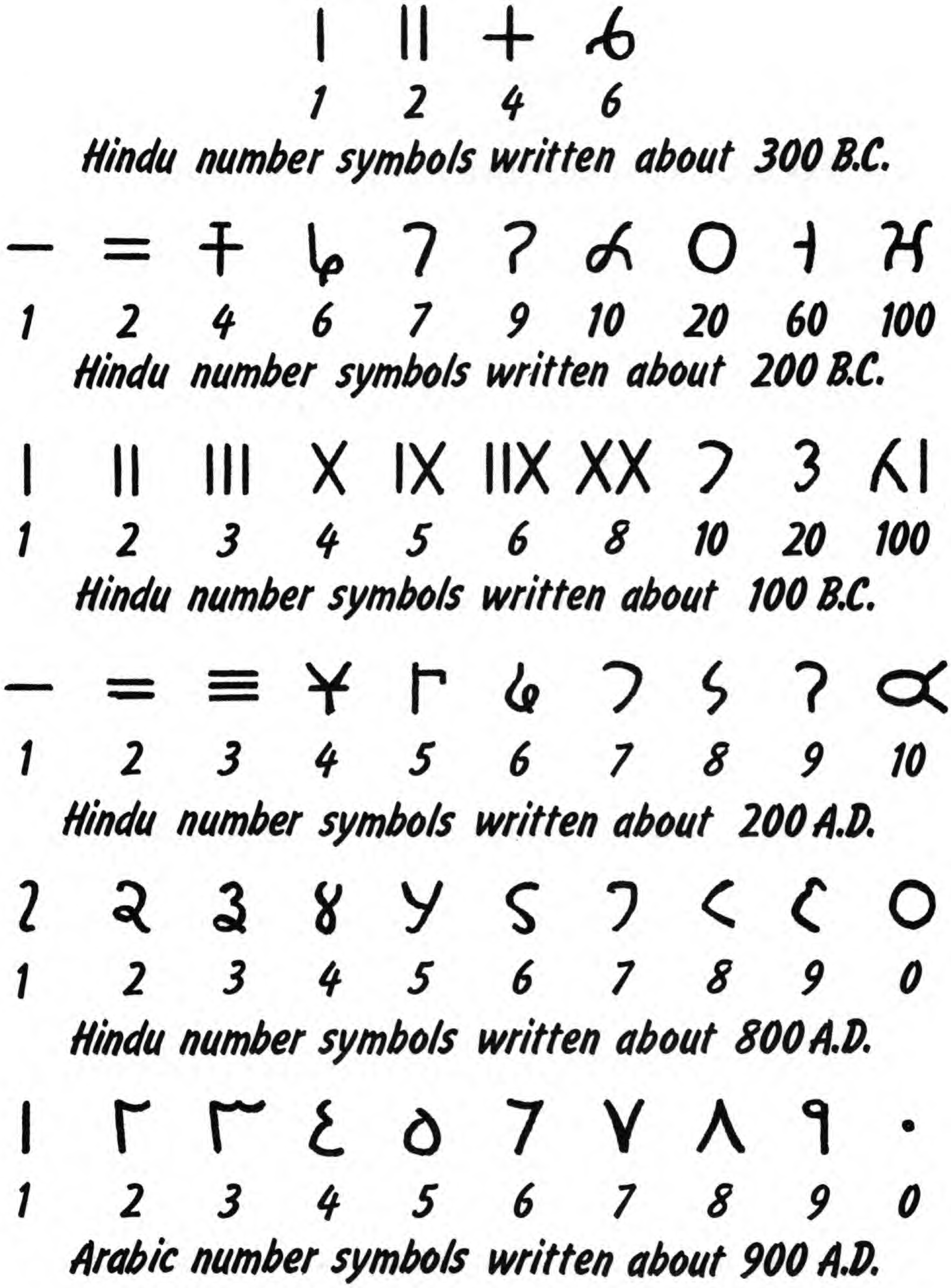


Fig. 8. Development of early Hindu-Arabic written number symbols.

on this board with a cane pen filled with white ink. The advantage of the dust calculating tablet and the blackboard was that both could be erased quickly and easily.

Perhaps the greatest mathematical achievement of the Hindus was the development of the "zero" symbol. Their early symbol for zero was a dot.

Arab traders and merchants traveling through the Moslem Empire adopted the Hindu methods of writing numerals and calculating with these numerals. But carrying abacuses or blackboards for computing proved to be a burden, so the Arabs resorted to the use of a newly developed material—paper. Paper was costly and erasers had not yet been invented; hence when the Arabs made a mistake in writing their numbers, they merely crossed them out and wrote the correct numbers above them.

Finger symbols for numbers continued to be used in Spain, Italy, and Germany during the period from 1200 A.D. to 1600 A.D. (The Greeks, Romans, and Chinese had also used finger signs to represent numbers.) Spanish and German textbooks written during this period show finger symbols that had to be learned if one were to bargain in the market places (Fig. 9). In many countries—other than in western Europe and on the North American continent—finger symbols are still used in counting and calculating.

The use of knotted cords to record numbers also was common in Europe. In Germany the amount of grain in a sack was shown by the type of knot tied to the sack to keep it

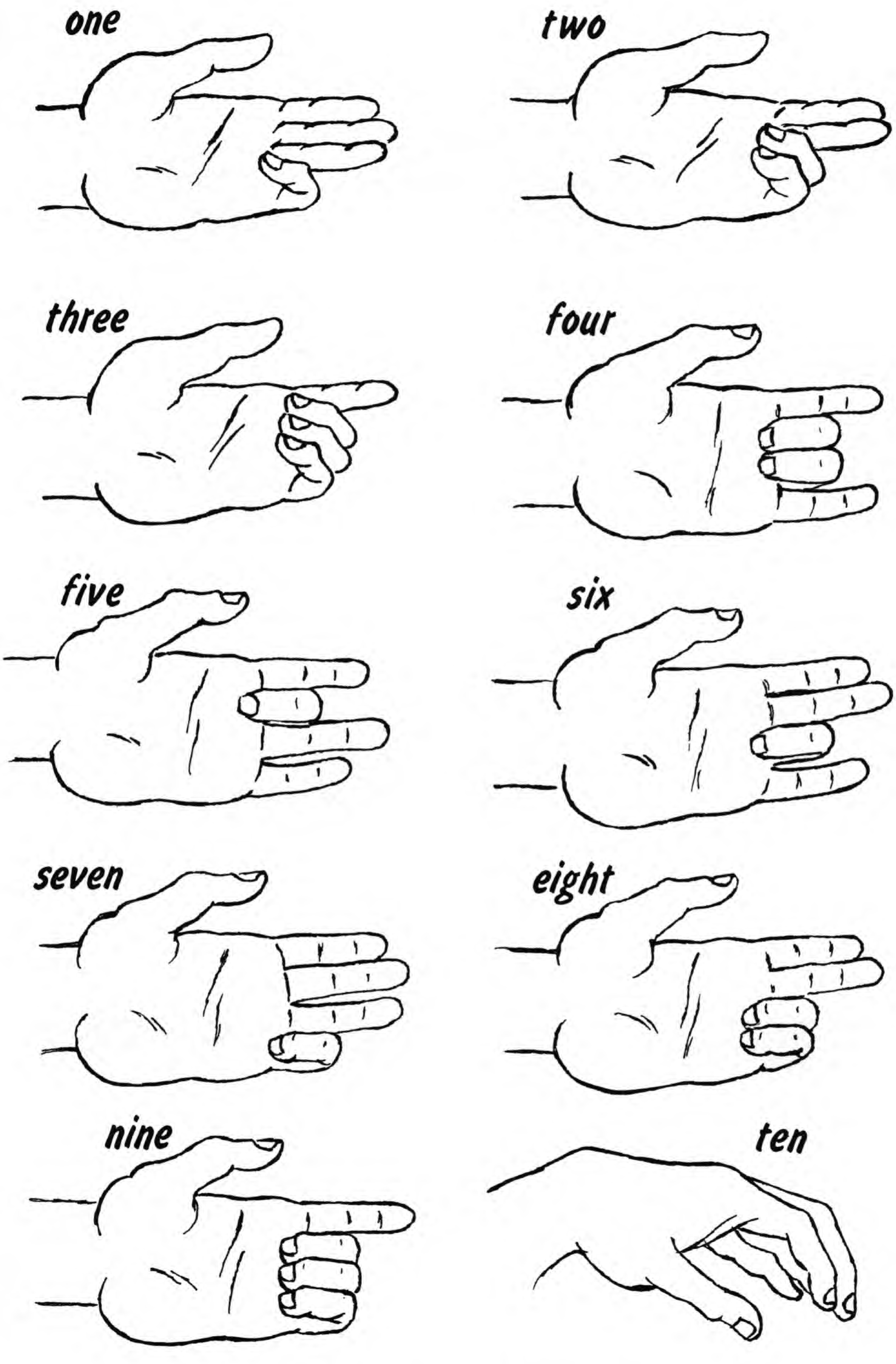


Fig. 9. Finger symbols for numbers.

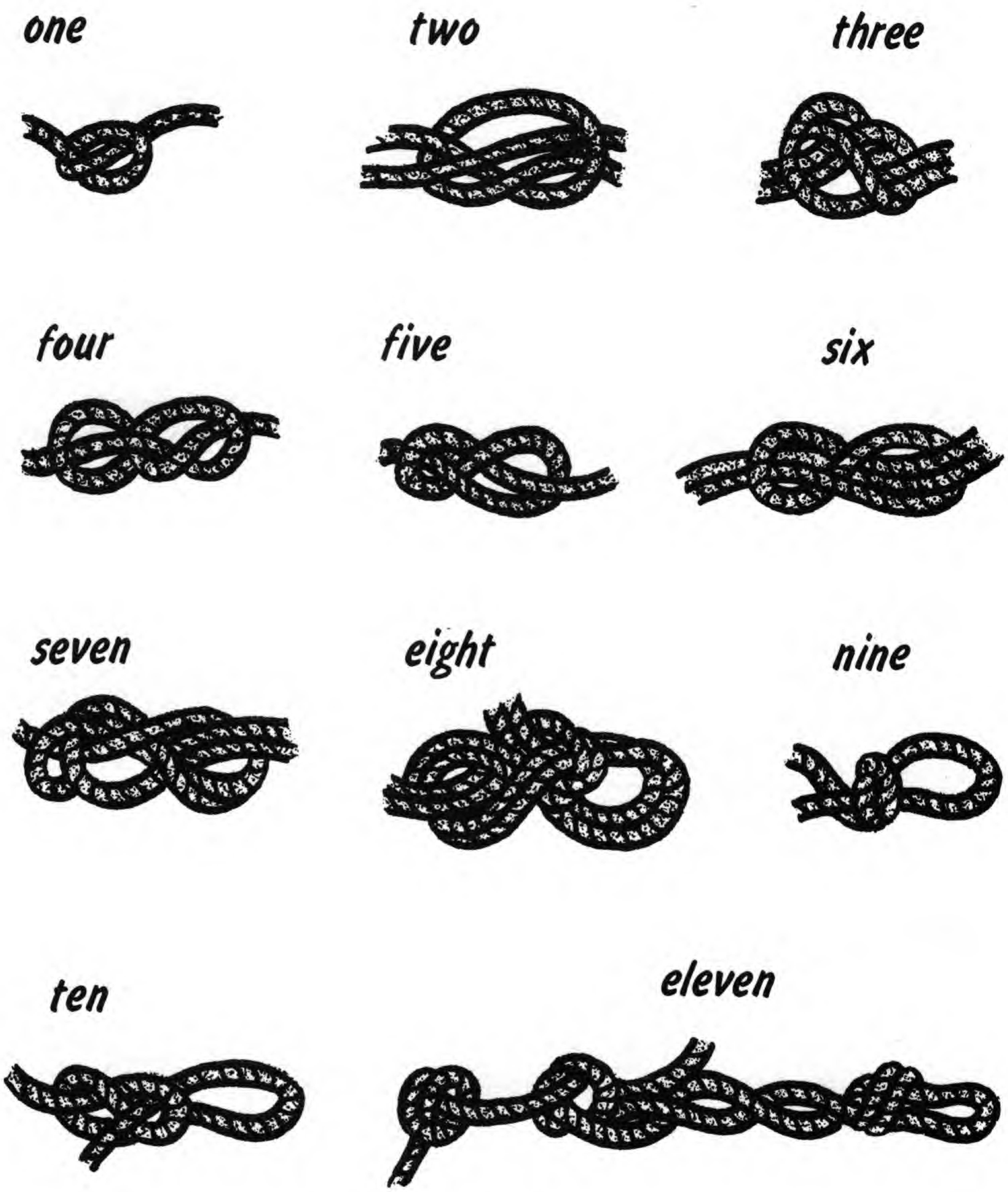


Fig. 10. Knotted cords used to record and designate numbers.

closed. Each knot shape had a numerical meaning (Fig. 10).

During the 1500's the Peruvians also used knotted cords to record numbers. Problems were calculated on counting boards and their results permanently recorded on cords.

The first mechanical calculating device was invented sometime around 1642 A.D. by Blaise Pascal, a French philosopher, mathematician, and physicist. Pascal designed and constructed an adding machine that used a number system based on 10. The device involved a simple wheel arrangement that actually counted numbers rapidly. Later in this book you will learn how to make a "stepped-wheel" calculator similar to Pascal's.

Later in the 1600's another mathematician, Gottfried von Leibnitz, discovered that all decimal numbers could be represented by using only the symbols 1 and 0. His method of recording numbers is called the binary system. Instead of using multiples of 10, such as 1, 10, 100, 1,000, etc., he used multiples of 2—1, 2, 4, 8, etc. (see Fig. 11).

In the decimal system as a digit is shifted one place to the left, its value is multiplied by ten. But as a symbol in von Leibnitz's binary system is moved one place to the left, its value is multiplied by two. The binary symbol 10 indicates the quantity 2 because of the placement of the 1. The decimal number three is expressed in the binary system as 11. The right-hand 1 stands for a value of 1; the left-hand 1 stands for a value of two. Adding these together we get the decimal number 3.

binary system	2x2x 2x2	2x2x2	2x2	2	1	decimal equivalent
	16	8	4	2	1	
					1	1
				1	0	2
				1	1	3
			1	0	0	4
			1	0	1	5
			1	1	0	6
			1	1	1	7
		1	0	0	0	8
		1	0	0	1	9
		1	0	1	0	10
		1	0	1	1	11
		1	1	0	0	12
		1	1	0	1	13
		1	1	1	0	14
		1	1	1	1	15
	1	0	0	0	0	16
	1	0	0	0	1	17
	1	0	0	1	0	18
	1	0	0	1	1	19
	1	0	1	0	0	20

Fig. 11. Decimal numbers and their binary equivalents.

Because you are so used to calculating with the decimal system, it will probably be necessary for you to study the table in Fig. 11 for a short time before the binary system becomes clear to you. Just remember that as the symbol 1 shifts one place to the left, its value is always multiplied by two. Notice the binary symbol for the decimal number 20, for instance. Here the 1 in the fifth column to the left represents 16 and the 1 in the third column to the left represents 4, for a total of 20.

Let's try using the binary system to add the decimal numbers 7 + 5 + 8 + 10 + 3. The problem would look like this:

BINARY	DECIMAL
111	7
101	5
1000	8
1010	10
+11	+3
100001	33

In the binary answer the 1 at the left represents 32 and the 1 at the right represents 1, which added together make the decimal total of 33.

A multiplication problem in binary numbers might look like the one shown at the top of page 22.

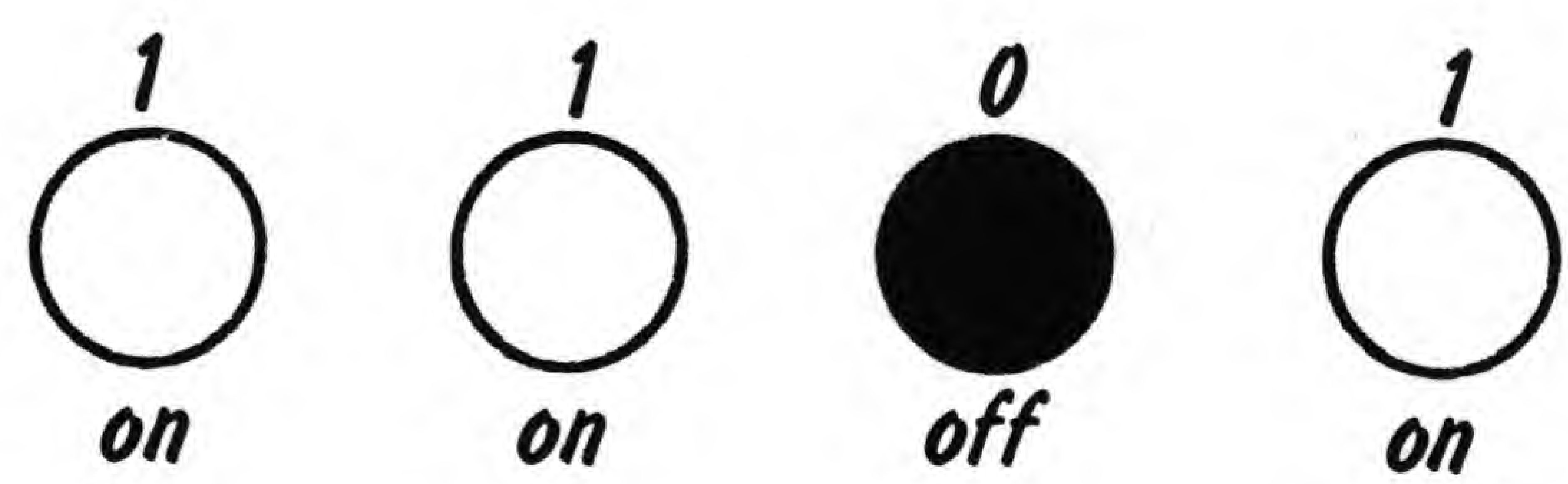
It is fairly easy to see why von Leibnitz's binary system did not find much usage during his lifetime! Although the system utilized only two symbols, many more columns were

BINARY	DECIMAL
11011	27
×1101	×13
11011	81
11011	27
11011	351
101011111	

needed to write numbers. For example, in the multiplication problem above it took five places in the binary system to represent 27, four places to represent 13, and nine places to express the answer 351. The use of so many places to express a simple number proved to be a disadvantage until recent years.

Today the binary system has found new favor, because the only two symbols necessary to the system can be related to an electric circuit, where only two states are possible, on and off. The on state of the circuit can represent 1 and the off state of the circuit can represent 0.

If light bulbs are connected to the off and on switches, the binary number 1 is represented when the circuit is closed and the light is on. When the circuit is open and the light is off, the binary number 0 is represented. Using light bulbs and switches, the decimal number 13 would appear like this in electrically expressed binary numbers:



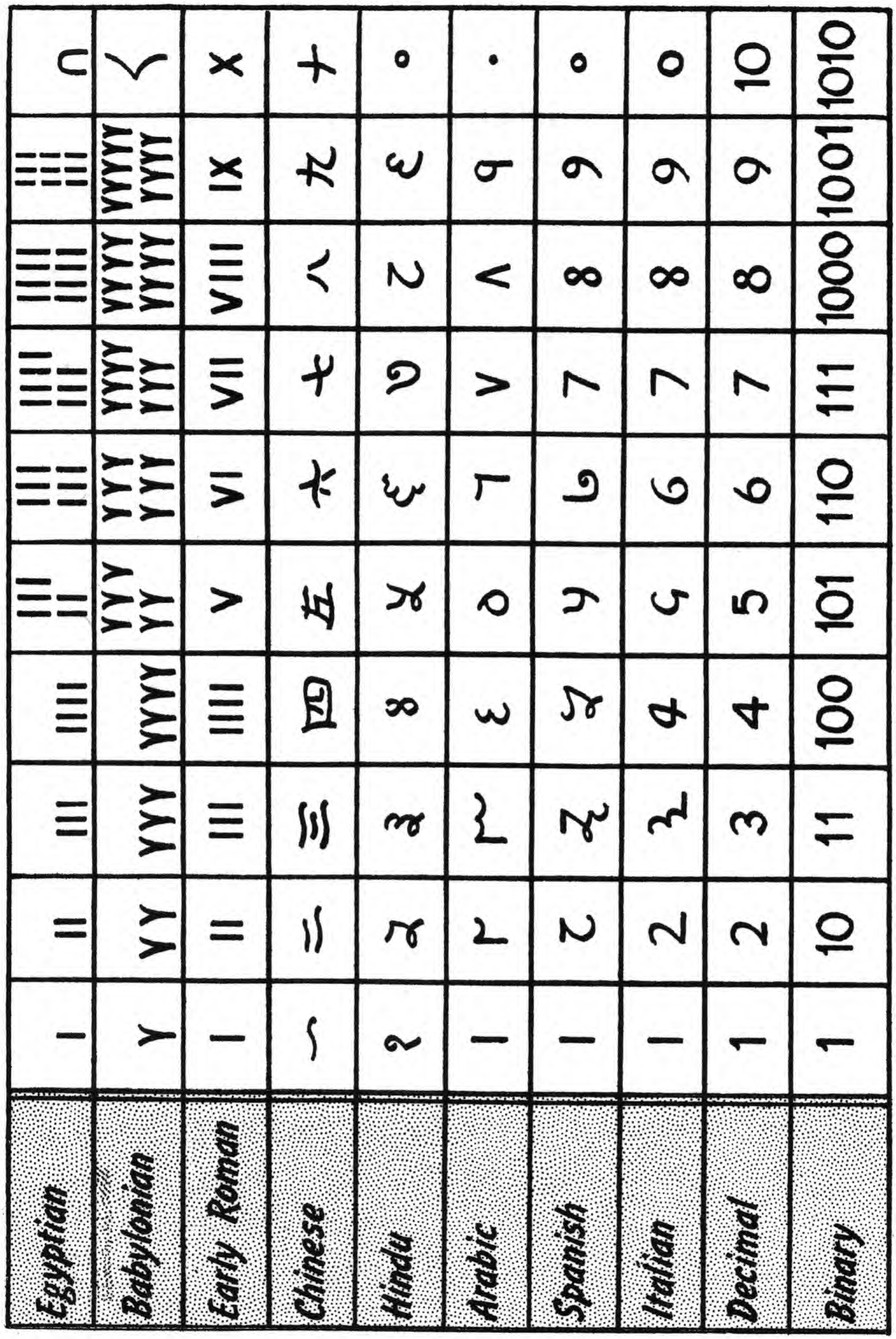


Fig. 12. The development of written numbers.

Present-day electronic computers can accept binary numbers and deliver answers in decimals or accept decimal numbers and give binary answers.

The development of calculators and computers is much like the history of other areas of science and mathematics. Rocketry, radar, atomic energy, and jet propulsion also had simple beginnings. Today's advances in all these fields are the results of the accumulated efforts of many men of many times and many parts of the world whose work has been combined to give us the scientific machines in use today.

The Story of Modern Computers

After the seventeenth century, little was done for two hundred years to improve the then crude methods of calculation. But there was no real need to do thousands of mathematical problems a minute. So man continued to compute with pen and ink on paper.

However, in the nineteenth century, Charles Babbage, an English mathematician, foresaw the need for a machine that would be capable of doing thousands of calculations in sequence. From 1820 to 1823 Babbage worked on drawings for a calculator, or "engine," as he referred to it, that would solve complex mathematical problems. The Royal Society, an English scientific organization to which Babbage belonged, secured money from the British government to

aid him in financing his work. With this money he continued his experiments. However, he soon found that the craftsmen of his time could not produce the accurate parts needed to make his calculator work. He was further disappointed when the government refused to give him additional money, and by 1856 he had discontinued his construction of the calculator.

Herman Hollerith, an American inventor and statistician with the United States Census Bureau, had read with interest of Babbage's experiments with calculators. He was disturbed by the fact that the census taken in the United States in 1880 was still being sorted, counted, and tabulated by paper-and-pencil methods in 1886. He knew this method was too slow and time-consuming.

To solve the problem of sorting, counting, and tabulating the results of the census, Hollerith invented a card containing punched holes that could be read by an electrical device. He punched the holes in the cards by hand. Each hole represented certain information, such as state, city, village, age, or occupation. After they were punched, the cards were fed into the electrical device, which sorted, counted, and tabulated the results. This was the first practical use of a digital computer.

The principle of Hollerith's 1889 punch-card calculating machine is used today in the enormously complex calculators and computers manufactured by the International Business Machine Corporation and by Remington Rand.

Present-day punch-cards are mostly of a standard size. Each is 3 1/4″ wide, 7 3/8″ long, and 0.0065″ thick (Fig. 13). The punch-card has room for 80 columns along its 7 3/8″ length, and as many as ten holes can be punched in each of the 80 columns across its 3 1/4″ width. There is also space on the card where information read from the holes can be printed.

All the data to be computed or recorded are first assigned a space on the cards. Then a key punch machine, which looks something like a typewriter, punches the holes in the cards. After all the data are converted into punched holes, the cards can be sorted, filed for future use, or fed directly into a computer to calculate pay checks, amounts due on bills, payments received on bills, or numerous other calculations that would take a great deal of time if done manually.

When a card is fed into the computer, this is what happens: The punch-card passes between a roller carrying electrical current and a series of brushes which can also carry electrical current. When a punched hole passes between the roller and a brush, the electrical circuit is completed. After the circuit is completed, the hole is considered read and the data recorded. (See Fig. 14.)

The machines that process punch cards are called data-processing machines, or more commonly, digital computers. The simplest form of digital computing is counting on the fingers. A digital computer also determines quantity by means of counting—it does this by counting the holes in the

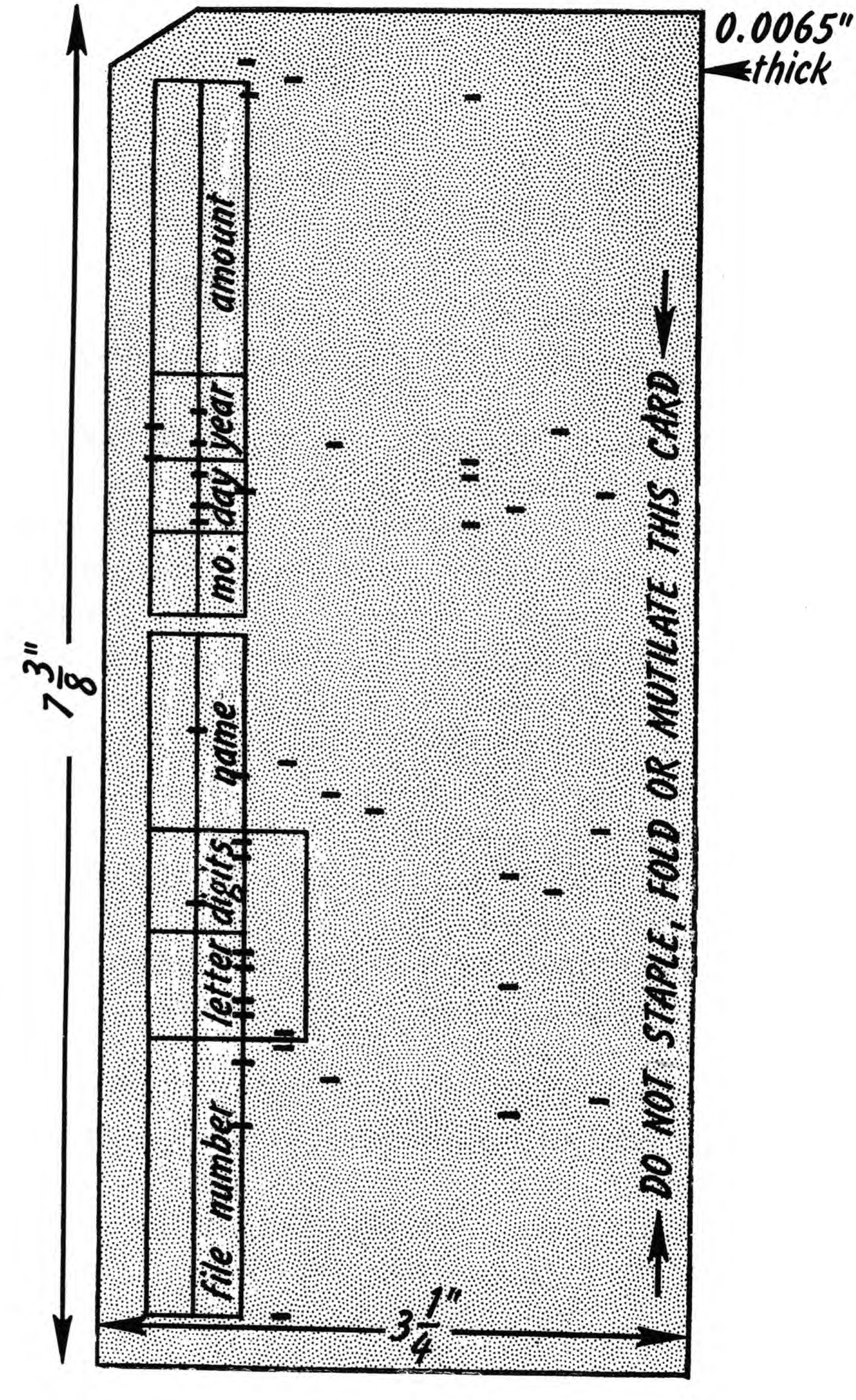


Fig. 13. Standard punch-card.

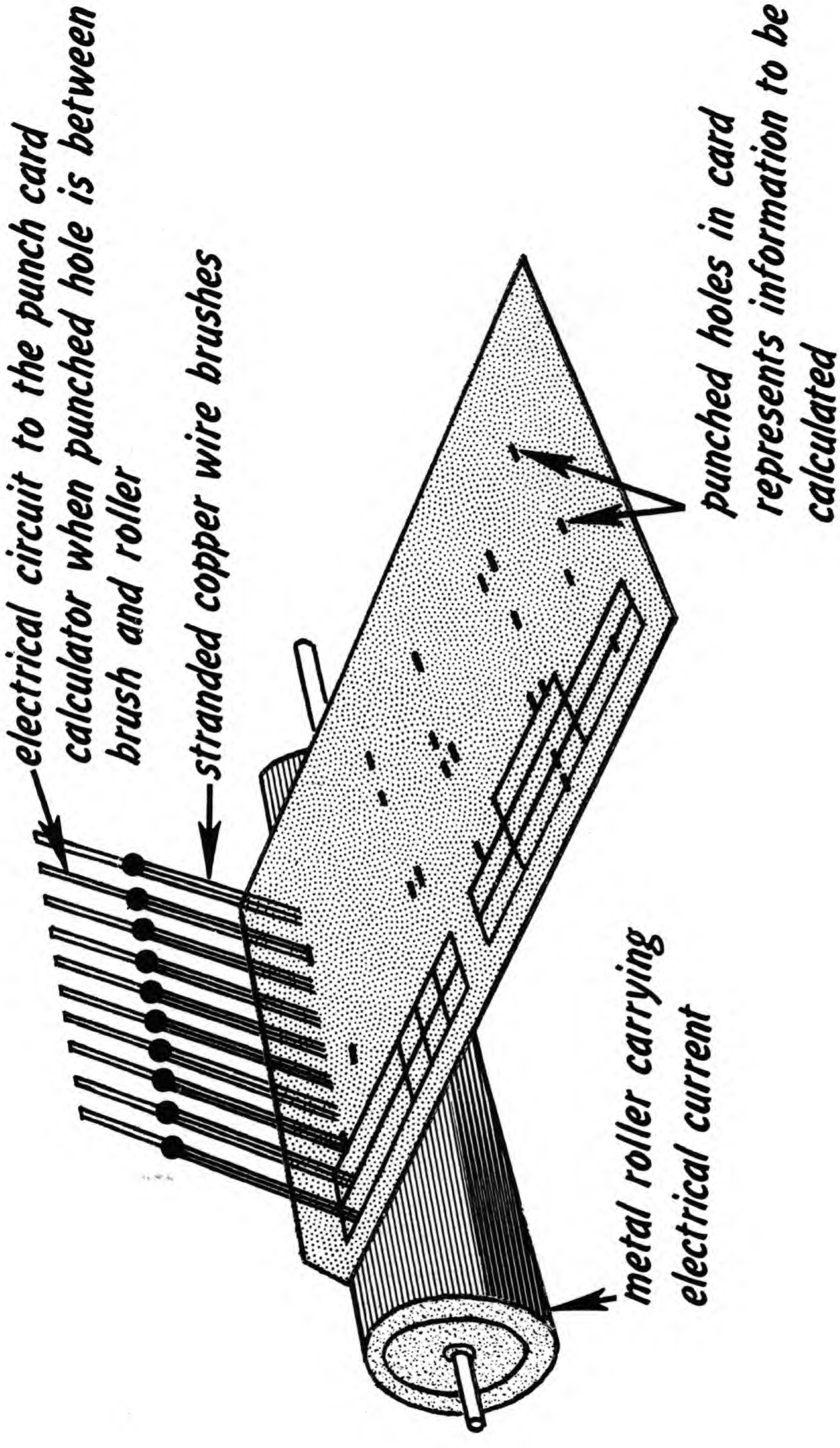


Fig. 14. Reading a punch-card.

card. The machine also takes into account the *placement* of the holes.

Today's electronic digital computers are immensely complicated machines which are composed of five separate parts: input, control, storage, processing, and output (Fig. 15).

PROGRAMMING

Before any information is fed into an electronic computer, a scientist or mathematician called a programmer must work out a simple step-by-step set of instructions for the machine to follow. This set of instructions is termed a program. The job of preparing information for the computer usually takes a great deal longer than finding the answer to the problem. The programmer must be accurate and must recheck his information. Data fed into the machine which are incorrect will only give incorrect answers. But when the correct information is given the computer, it can calculate the answer in a fraction of a second.

INPUT

When the programmer enters numbers, symbols, or letters into the computer, the process is called input. The input section of the machine accepts information in the form of manually operated switches, magnetic tapes, paper tapes, or punched cards.

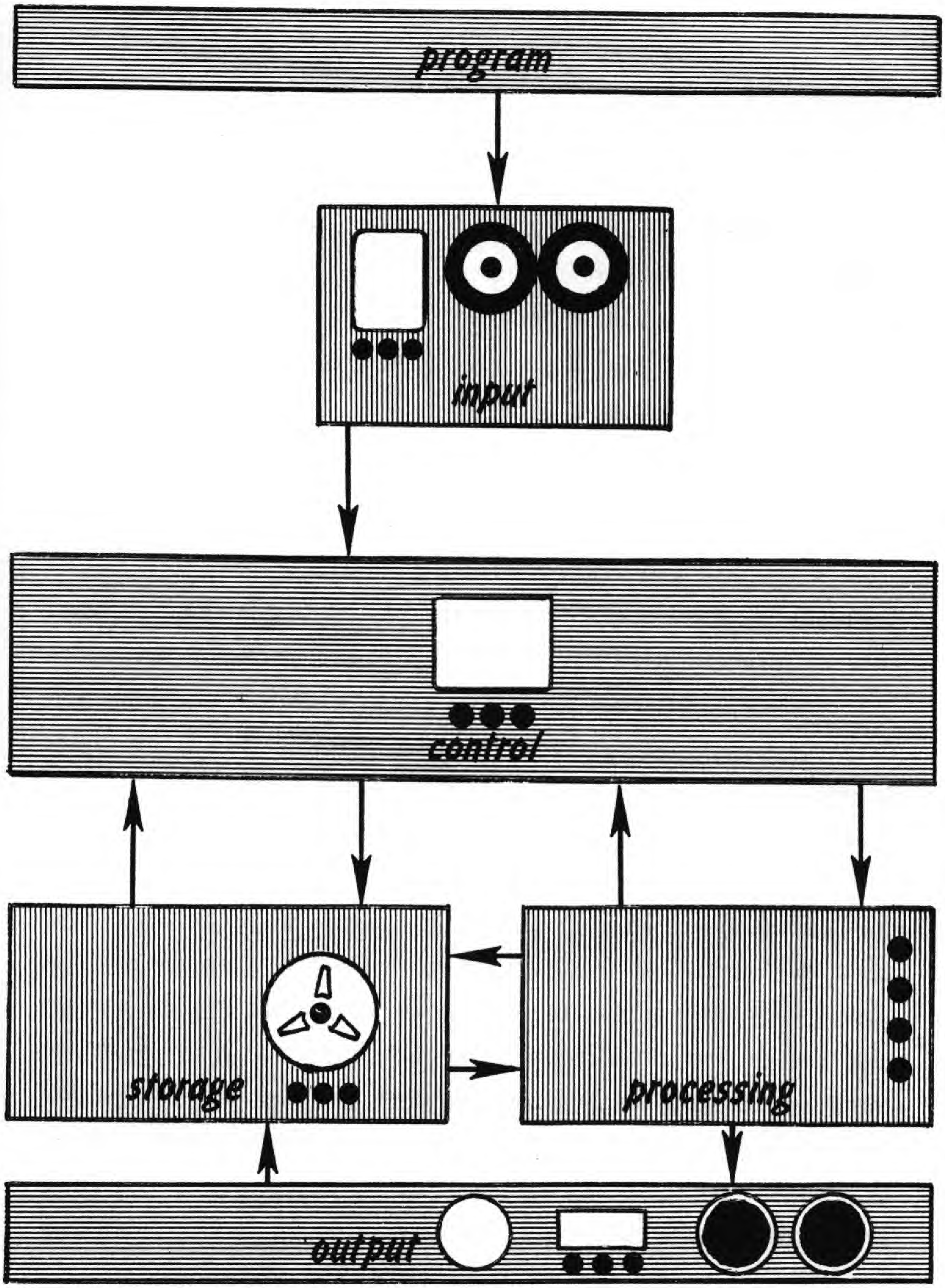


Fig. 15. The parts of a digital computer.

CONTROL

Previously prepared step-by-step instructions which determine the sequence in solving the problem go to the control unit of the computer. The control unit then directs the instructions to the processing unit or the storage unit of the computer. When the program or set of instructions is filed in the computer for future use, it is termed a "stored program."

STORAGE

Each step of the program has an address or a specific location where it is to be stored in the storage unit. The storage unit retains the information with the aid of magnetic, electro-magnetic, or electrical devices until called upon by address to deliver the information to other parts of the computer.

The devices that file information in the storage unit are referred to as memory devices. Three types of memory devices are used: the cathode-ray memory tube, the magnetic core, and magnetic tape. The cathode-ray memory tube is much like the picture tube in your television set. It has an electron gun which directs negative charges at a target plate coated with dots to hold the charges (see Fig. 16). Depending upon what data the memory device is to retain, some dots on the plate are charged, others are not. When the tube is called upon to give back information, the beam from the

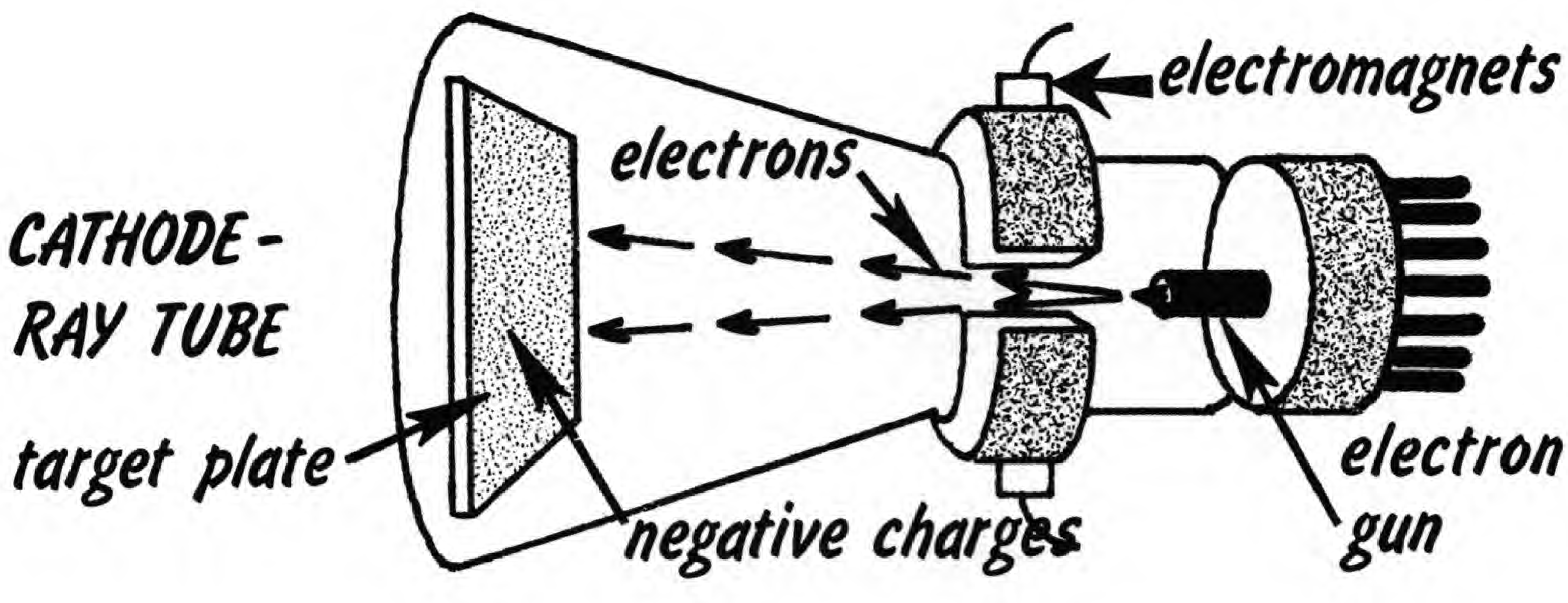


Fig. 16.

electron gun reads the dots. Dots that have been charged repel the beam and are recorded.

Although the cathode-ray tube records, retains, and supplies information very quickly, an electrical failure would cause all previous work to be lost in storage. It therefore is used only when data are to be stored temporarily.

The magnetic core is one of the newest memory devices. This is composed of tiny ringlike magnetic cores through which current-carrying wires are threaded (see Fig. 17). Scientists refer to these cores as ferro-magnetic rings (ferro means iron).

Electric current traveling through the wires in one direction induces a field of magnetism in the rings, and after the current is shut off the ring remains magnetized. When electrical current is passed in the opposite direction through the

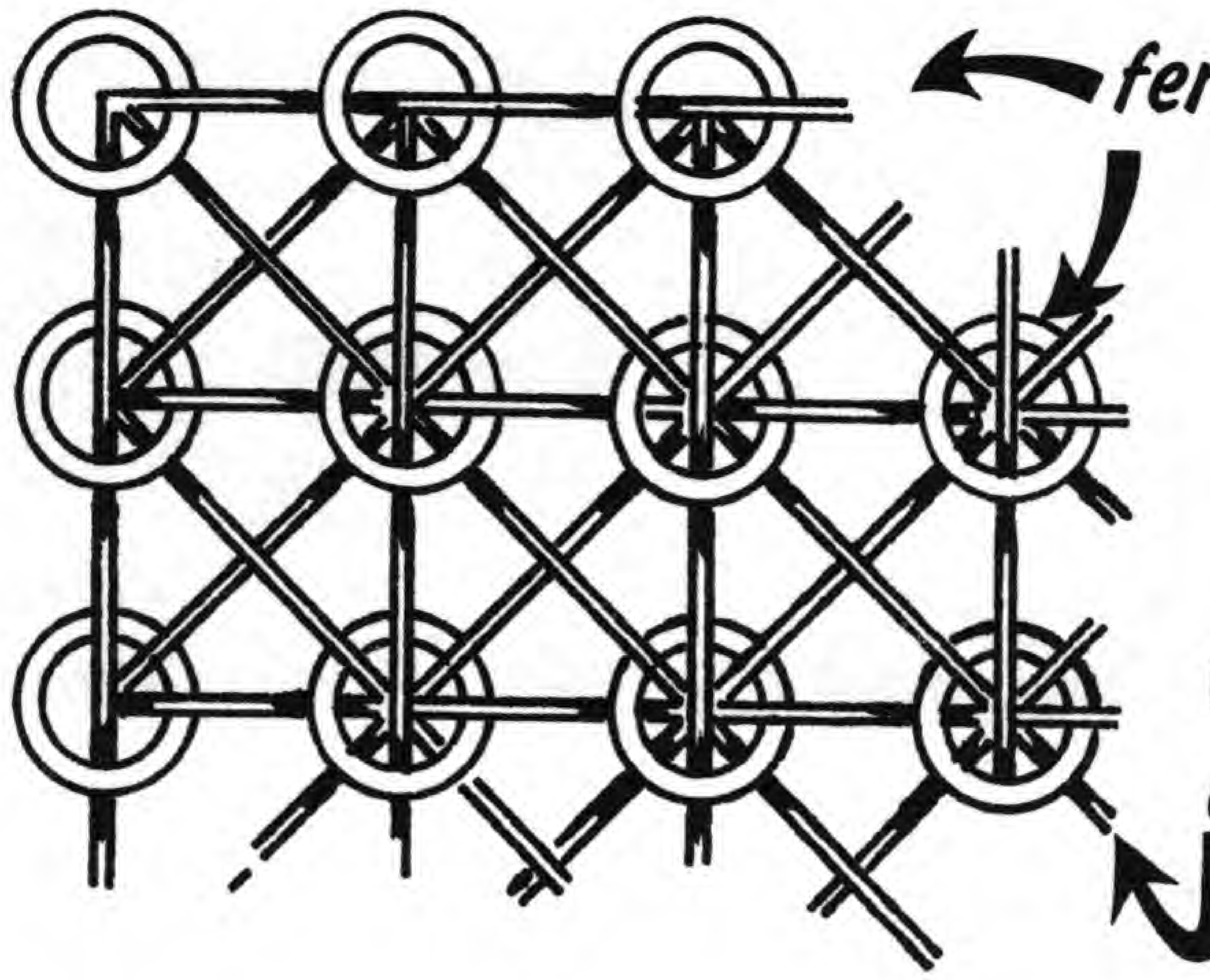


Fig. 17.

wires, the field of magnetism in the ferro-magnetic rings is reversed.

This dual direction of the fields of magnetism set up in the rings can be related to the binary number system. A magnetic field in one direction can represent the 0, while a magnetic field in the opposite direction can represent the 1.

A single magnetic-core memory unit consists of about 704 threaded ferro-magnetic rings, which can store up to 168,000 pieces of information. Scientists refer to these pieces of information as "bits." A number of memory units containing millions of "bits" of information can be stored in a single storage unit. When the memory units are called upon to give up information, pulses of current racing through the wire-

threaded cores read the direction of the field of magnetism stored on the ferro-magnetic rings. A magnetic-core unit can be read by this method within a few millionths of a second.

The new magnetic-tape memory device consists of a 1/2″ wide strip of plastic or metal tape divided into vertical and

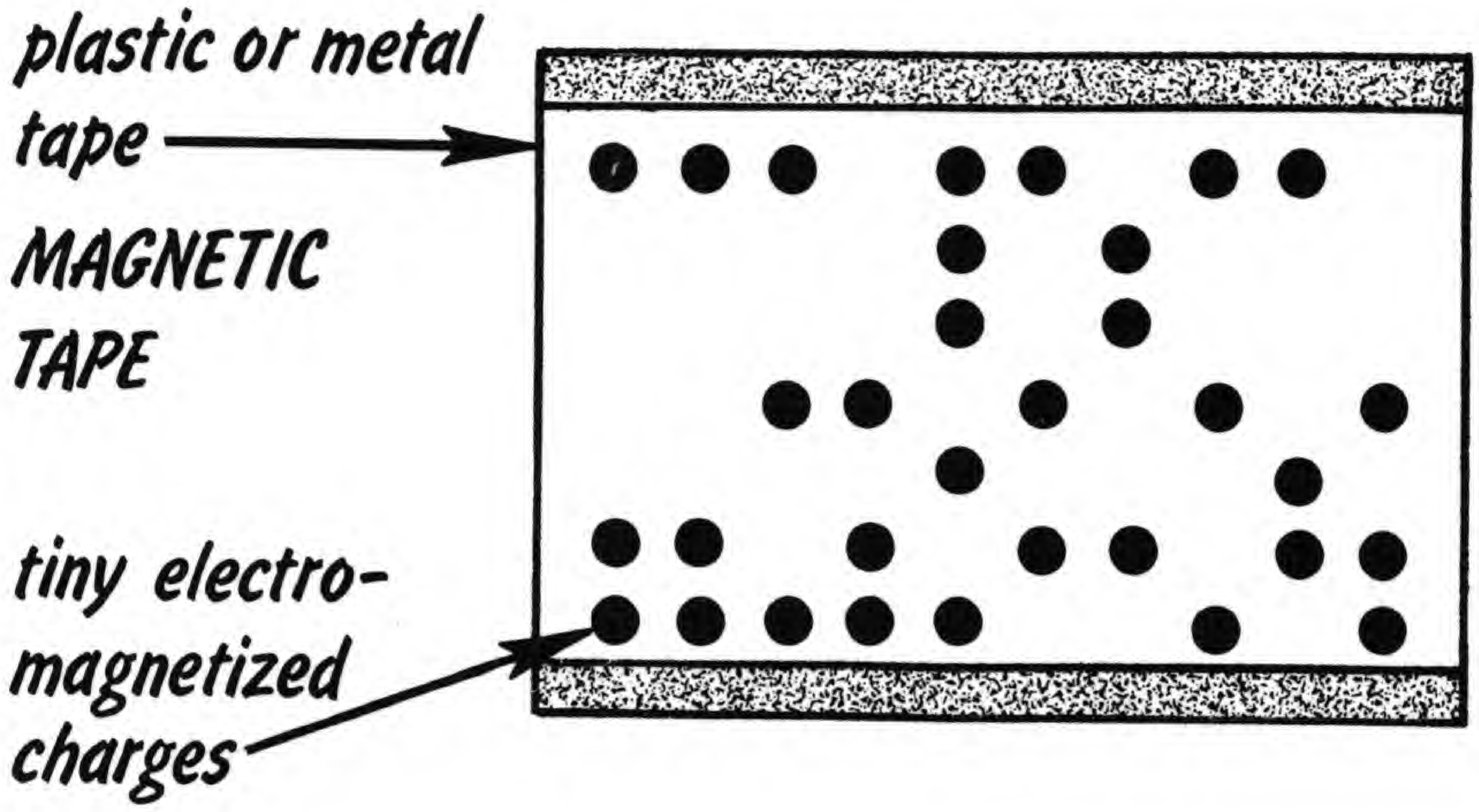


Fig. 18.

horizontal tracks that are coated with material which accepts and retains magnetism (see Fig. 18). Along a seven-track tape 2400 feet long it is possible to record millions of "bits" of information.

Seven pin-point size electromagnets wound with two magnetic coils, a "write" coil and a "read" coil, are placed

just above the tape so that there is one set of coils for each track. Each electromagnetic coil consists of a soft iron core around which is wound extremely fine copper wire.

If the tape is to be written upon, current passing in one direction through the "write" coil induces a tiny North-South field of magnetism on one spot of a track on the tape. If the direction of the electric current is reversed, a tiny South-North field of magnetism may be induced on the tape.

When the magnetic tape is read, the tiny magnetic spots along the tracks of the tape induce pulses of electric current in the "read" coils. The direction of the weak current induced in the "read" coils is recorded and the current is amplified by other electronic devices as it travels through the computer.

The South-North and North-South direction of the magnetism can be related to the 1 and 0 of the binary number system. A variation in the use of the magnetic tape as a method of storage is to magnetize or not magnetize spots on the tracks of the tape. Thus the presence or absence of magnetism on a spot can also represent the 0 or 1, or "yes" or "no," condition used by computers to solve problems.

PROCESSING

Following instructions from either the control unit or the storage unit of the computer, the processing unit does rapid

addition, subtraction, division, and multiplication calculations at the rate of millions a minute. The processing unit then directs these calculations back to the control unit, or to the storage unit if the information is to be retained for future use, or directly to the output if the data are to be used immediately.

OUTPUT

Answers to problems or data programmed into the computer are recorded by the output unit by means of punch-cards or magnetic tape and printed in readable form. Sometimes the information given by the output unit is again put through the computer to recheck its accuracy.

The five parts of the modern digital computer discussed above can be compared to the process you use in school to solve mathematics problems. The problem that has been set down in the book has been programmed by the writer of the book. The information you are given in the problem can be compared to the input process of the computer. The control unit is like the rules and tables you have learned in arithmetic classes. These rules and tables tell you how and through what methods the problem is to be solved. The actual subtraction, addition, multiplication, and division you do to solve the problem are similar to the work done in the processing unit in the computer. As you record the steps

in solving the problem on paper you are performing a process similar to placing information in the storage unit of the computer. Your final written answer to a problem can be compared to the output of the digital computer.

So far in this chapter we have been reading about digital (or counting) computers. Now we proceed to a different kind.

In 1925 Vannevar Bush and several other scientists at the Massachusetts Institute of Technology began developing a new type of computer that they called an analogue computer. The word analogue stems from the word analogy, which may be defined as the comparison of two or more different things which, in particular circumstances, have a similarity on which such a comparison may be based. A simple example of this would be the analogy between the human heart and a mechanical pump.

The first analogue computer used moving geared wheels to do calculations. Each turn of the wheel equaled or had an analogy to a number.

Vannevar Bush's invention operated a great deal like the automobile odometer, which tells us how many miles we have traveled. A flexible cable from the automobile engine turns a shaft. The shaft meshes with gears on the odometer, and the odometer wheels then turn in relationship to the turning shaft. In this analogue computer one rotation of the odometer wheel is equal to the number 1.

At home you may have used analogue computations. As

you were growing up your parents may have marked your height on the door molding. Then they measured the distance from the floor to the mark on the molding to convert your height into feet and inches.

At school a length of string is sometimes used to measure the distance between two points on a globe. The string measurement is then compared to the scale of miles on the globe. In this case the length of string between the two points on the globe has an analogy to the distance in miles between the same two points.

By 1930 Vannevar Bush and his associates at the Massachusetts Institute of Technology had completed the first analogue computer. The first crude model was hand operated and had no electrical parts. The computer worked well, but Dr. Bush felt it could be improved.

In 1935 he began constructing another analogue computer. In this he utilized electrical connections to increase both the speed and accuracy of the calculations. For his new computer, Bush used the analogy that a unit of electricity, such as a volt, is equal to a number. The computer was completed in 1942 and put to use by military men to solve wartime problems.

Bush's computer quickly and accurately helped soldiers to figure the angles a field artillery gun had to be raised in order that the shell would travel the proper distance to the target. Another wartime use of this computer was to predict flight patterns of airplanes. A plane's speed, range, and di-

rection of flight, and the wind drift affecting it were fed into the computer. The output of the computer told antiaircraft gunners where the plane would be when they were ready to fire a round of ammunition at it.

An analogue computer has both an input and output similar to the digital computer. However, the analogue computer does *not:* (1) select the method of solving a problem, (2) store numbers for more than an instant, (3) accomplish steps in the solution of a problem that depend upon answers as they are given by the computer, (4) give completely accurate answers.

An analogue computer is used where a quick estimate of an answer to a problem is needed. The answer may be from 1 part in 1,000 up to 1 part in 100 in error.

Continuous measurements are fed into the input of the computer. This information is then translated into analogues through the use of gear ratios, shaft rotations, and electronic circuits. The computer's output then produces continuous answers which are recorded in the form of pen-and-ink graphs or shown on a series of dials.

To sum up, both digital and analogue computers solve problems. The digital computer solves problems by counting. The analogue computer solves problems by continuously measuring analogies through gear mechanisms and electronic circuits.

Digital computers can mark certain kinds of school tests, predict national and state election results from scattered

voting returns, solve complex mathematical problems, predict orbits of rockets as they travel through space, compute information from weather bureaus and make weather predictions, print checks for payrolls, compute and print bills, tabulate payment of bills, and do a multitude of other jobs in the fields of business, industry, and science. Analogue computers solve complex mathematical formulas, measure the amount of applause on radio and television programs, compile efficiency ratings of electronic parts, predict the effect in changes of airplane designs, analyze internal engine problems, and provide information for guidance systems in rockets, missiles, and airplanes.

It has been predicted that sometime in the future computers will be used in the home to select the daily menu; program cleaning, cooking, and other household chores; locate members of the family who are in other rooms; remind the family of doctor appointments, etc.; and perform other tasks around the home.

Construct Your Own Calculators and Computers

Many of the great truths of mathematics and science were first discovered by men who had only the simplest of materials. As they read, constructed, and experimented, they learned. You can share the experiences of some of these men of the past by constructing and experimenting with some of the mathematical devices with which they worked. Each of the projects that follow is a part of the history of calculators and computers.

The directions for constructing these mathematical devices are simple and easy to follow, and the materials and tools needed can usually be found around the house or are

readily available in hardware stores or hobby shops. However, should you have any trouble assembling the materials from sources nearby, they can be ordered from the list of supply houses given later in this book.

Although the dimensions given for the different parts can be varied considerably, try to follow them wherever possible, as changes in the dimensions may affect the operation of the device.

ORIENTAL ABACUS

The abacus has been the most widely used calculator in history. It has existed in many forms and in many countries for more than seven hundred years.

Recently it was demonstrated on television that a person experienced in using the abacus can do some mathematical operations, such as addition and subtraction, faster than a man using a modern desk calculator.

Let's build an Oriental abacus and then see if you can work out mathematical problems with it.

MATERIALS

- 63 wooden beads 3/8″ in diameter
- Nine standard-size paper clips
- 48 inches of 1/4″ x 1/4″ balsa or pine wood
- 6 1/8 inches of 1/8″ wooden dowel
- Model airplane cement for wood

TOOLS

- Single-edge razor blade or X-Acto knife
- Hand drill and two bits (one 1/64″ and one 1/8″)
- Flat-nosed pliers with side cutters
- Vise or clamps

Construct the inside frame of the abacus first. Measure and cut off four pieces of the 1/4″ x 1/4″ wood, two 6 1/8″ long and two 3 7/8″ long. Lay the 6 1/8″ pieces on the full-scale drawing (Fig. 19) and mark the placement of the holes for the paper clips. Now clamp these two pieces in a vise or clamps and using the 1/64″ bit and the hand drill, make the holes for the paper clips. Next lay the two 3 7/8″ pieces on the full-scale drawing and mark the placement of the holes for the wooden dowel. Put these two pieces in a vise or clamps and drill a 1/8″ hole through each.

The next step is to straighten the nine paper clips with the flat-nosed pliers. If straightened clips are slightly longer than those in Fig. 19, cut them to fit. When the clips are perfectly straight, string seven beads onto each. Lay the 6 1/8″ pieces of wood on a flat surface and insert the bead wires into the holes so that they are flush with the outside surface of the frame. Glue the wires into place.

Now insert the 1/8″ dowel (the reading bar) into the two 3 7/8″ lengths and glue in place. Separate the beads so that there are two on one side of the frame and five on the other, as shown in Fig. 19. Position the two shorter pieces of the frame so that the reading bar goes over the wires with the beads and glue them to the two longer lengths. Cut the pieces of the outside frame to size (shown in Fig. 19) and glue them to the inside frame. This outside frame makes the abacus more sturdy.

You are now ready to calculate on the abacus. The device

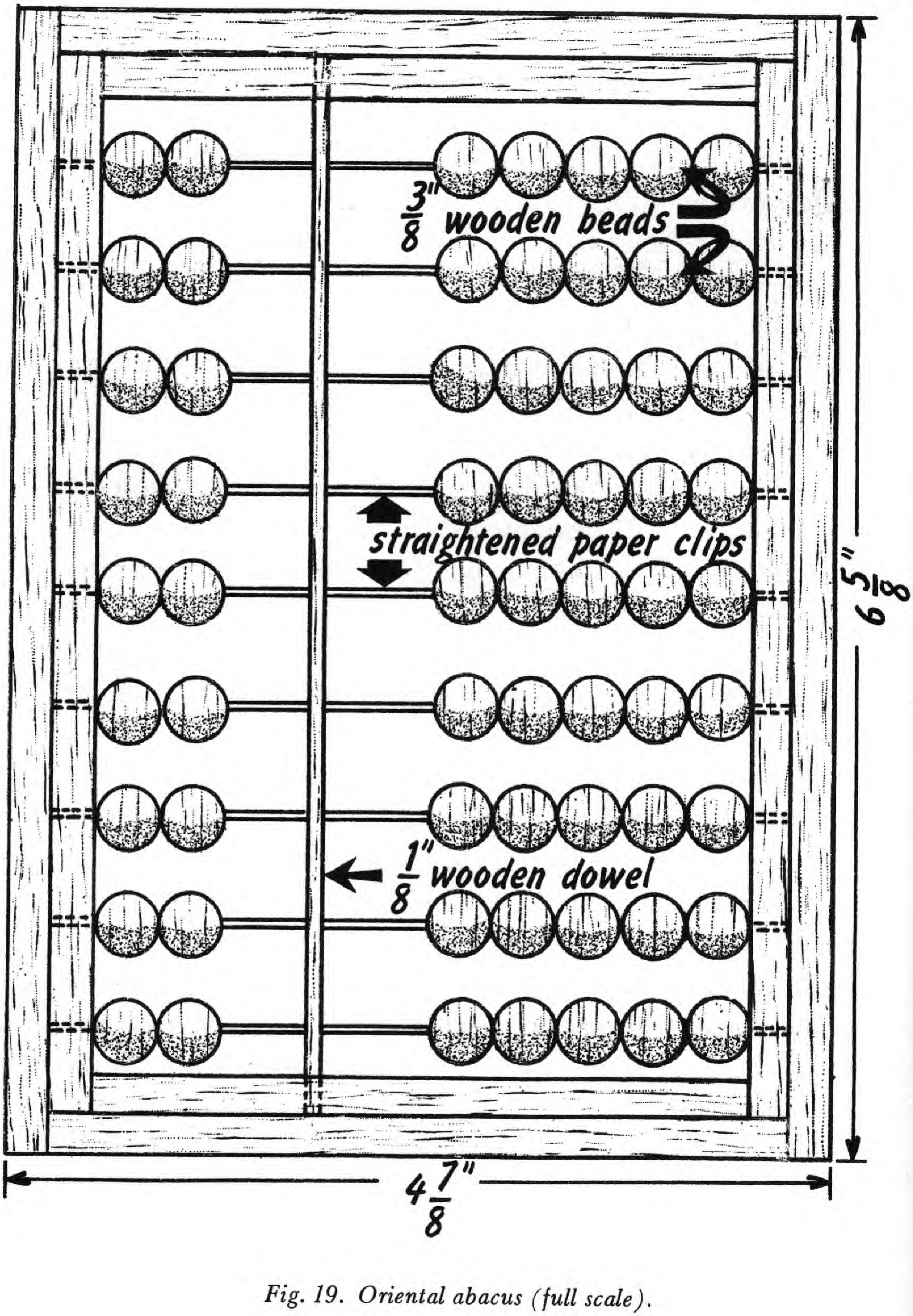


Fig. 19. Oriental abacus (full scale).

is simple to operate, but skill and practice are needed before you can calculate with it quickly and accurately. It must be remembered that much of the work is done mentally.

Hold the abacus in one hand and practice moving the beads up from the one area and down from the five area

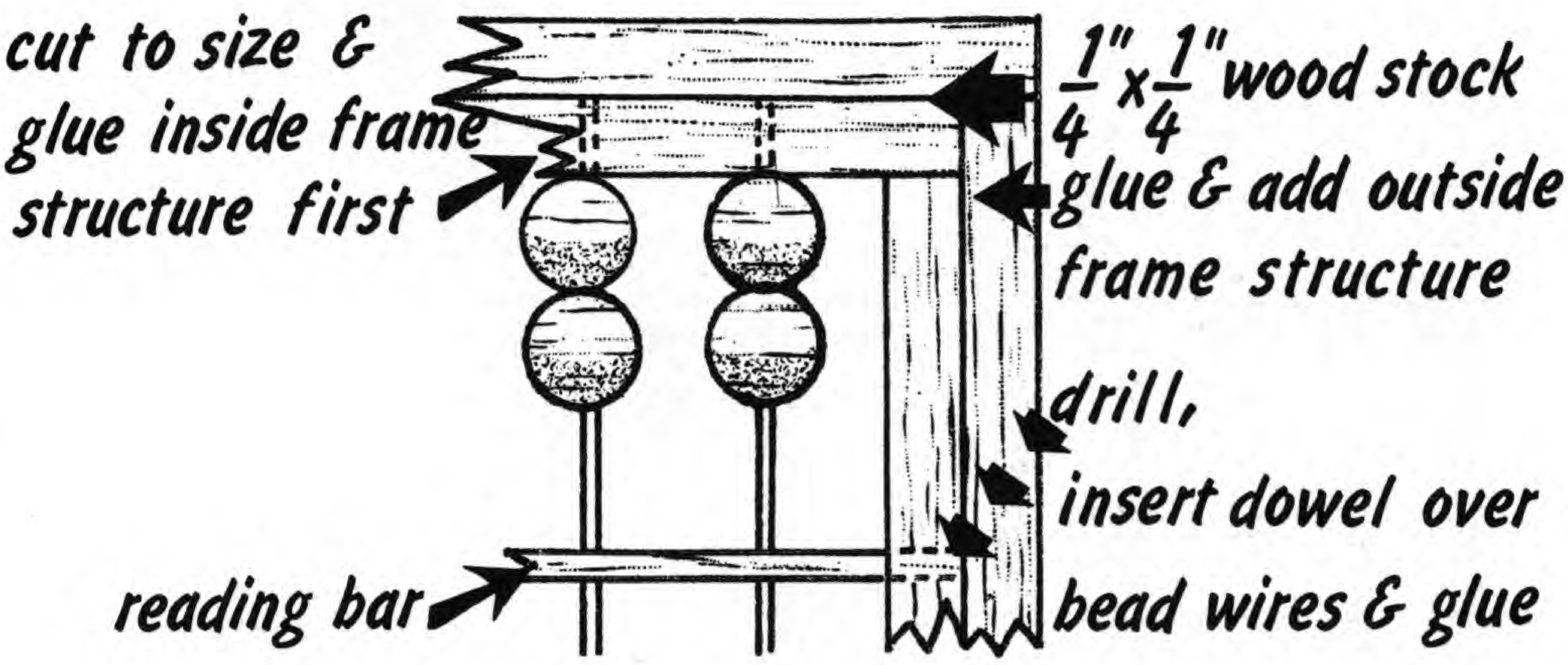


Fig. 20. Abacus construction detail (full scale).

with the thumb and forefinger of the other hand. Study the abacus number system (Fig. 21) so that you fully understand the place values. At first you might write these values along the frame of the abacus.

Try an addition problem. Add 486 plus 901 plus 32. Begin by recording the first number along the crossbar. Starting in the third column from the right, push up four lower

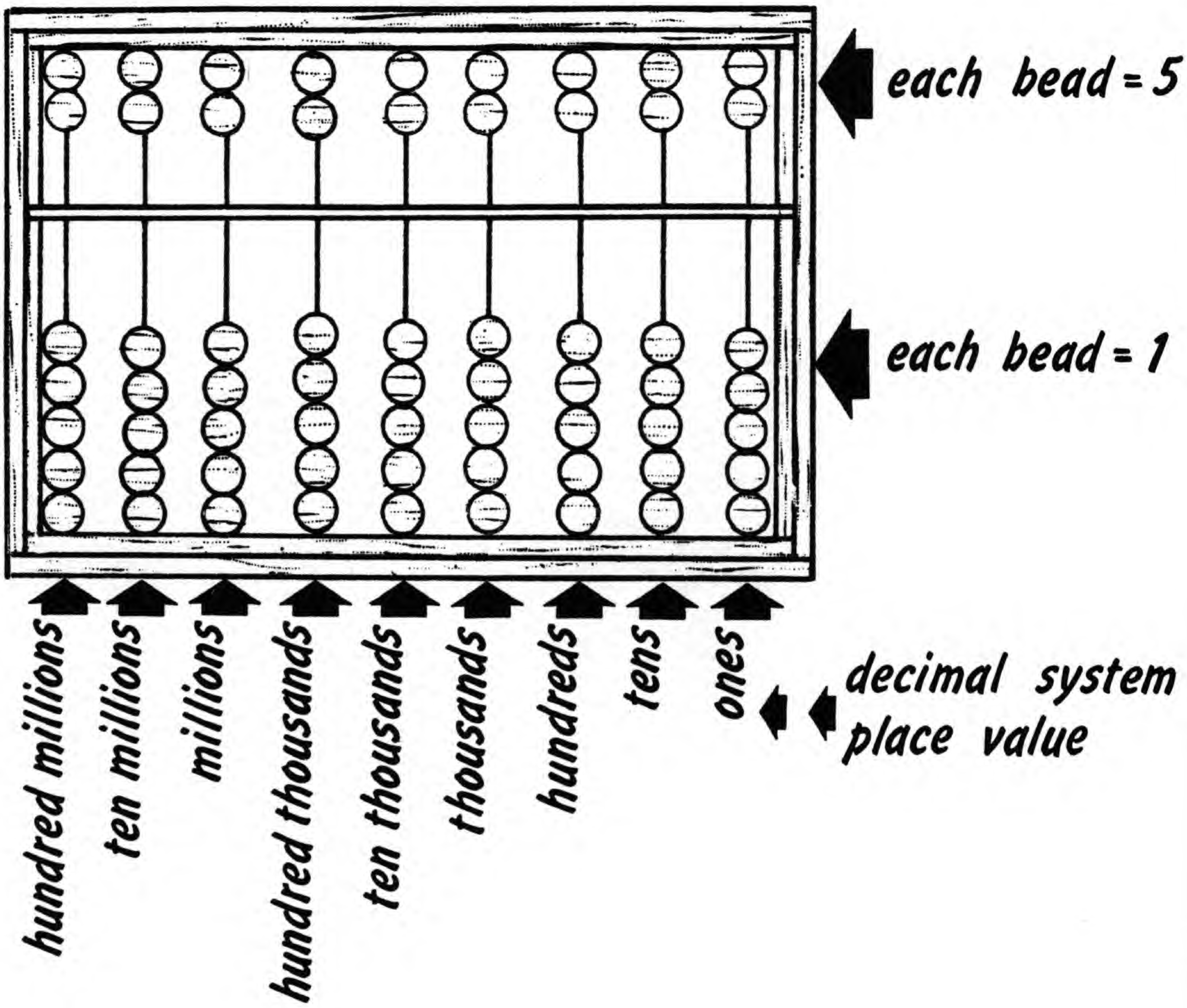


Fig. 21. Abacus number system (half scale).

beads for the four. In the next column to the right push up three lower beads and pull down one upper bead for the eight; and in the extreme right-hand column record the six with one upper bead and one lower bead. Remember that

the upper beads are worth 5, the lower ones 1. The number along the reading bar now reads 486. Check your results against the step-by-step calculating detail in Fig. 22.

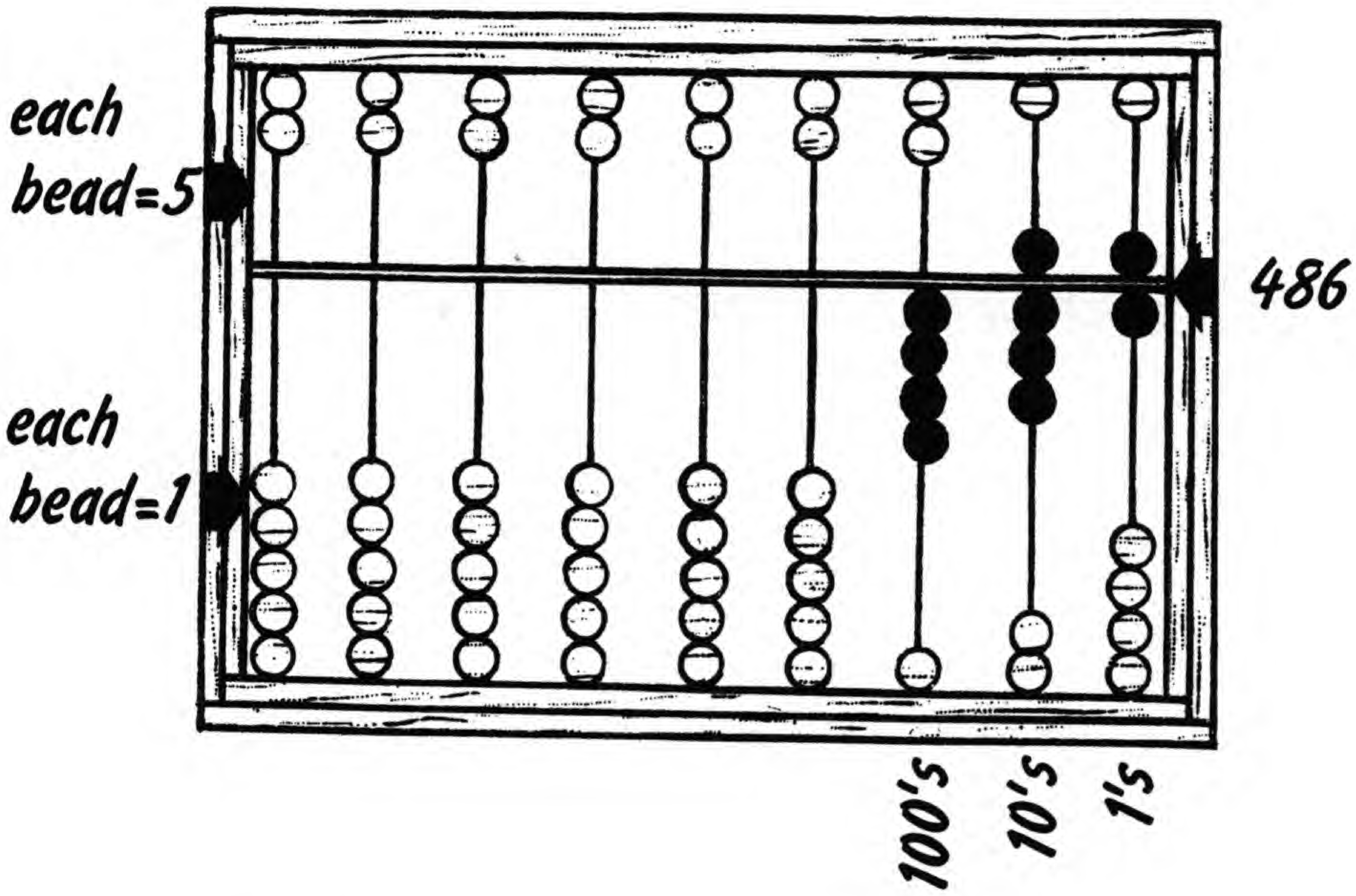


Fig. 22. Step-by-step calculating detail (half scale).

Start adding the 901 at the left, not the right. Adding the 9 to the 4 already on the abacus gives you 13, so move one bead down in the third column from the right, changing the 4 to a 3, and move up one bead in the fourth column, making 13. Since the next digit is 0, you don't have to

change the second column. Add 1 to 6 in the extreme right-hand column by pushing up one lower bead. Check your results with Fig. 23. The reading bar now shows one bead in the thousands column, three beads in the hundreds col-

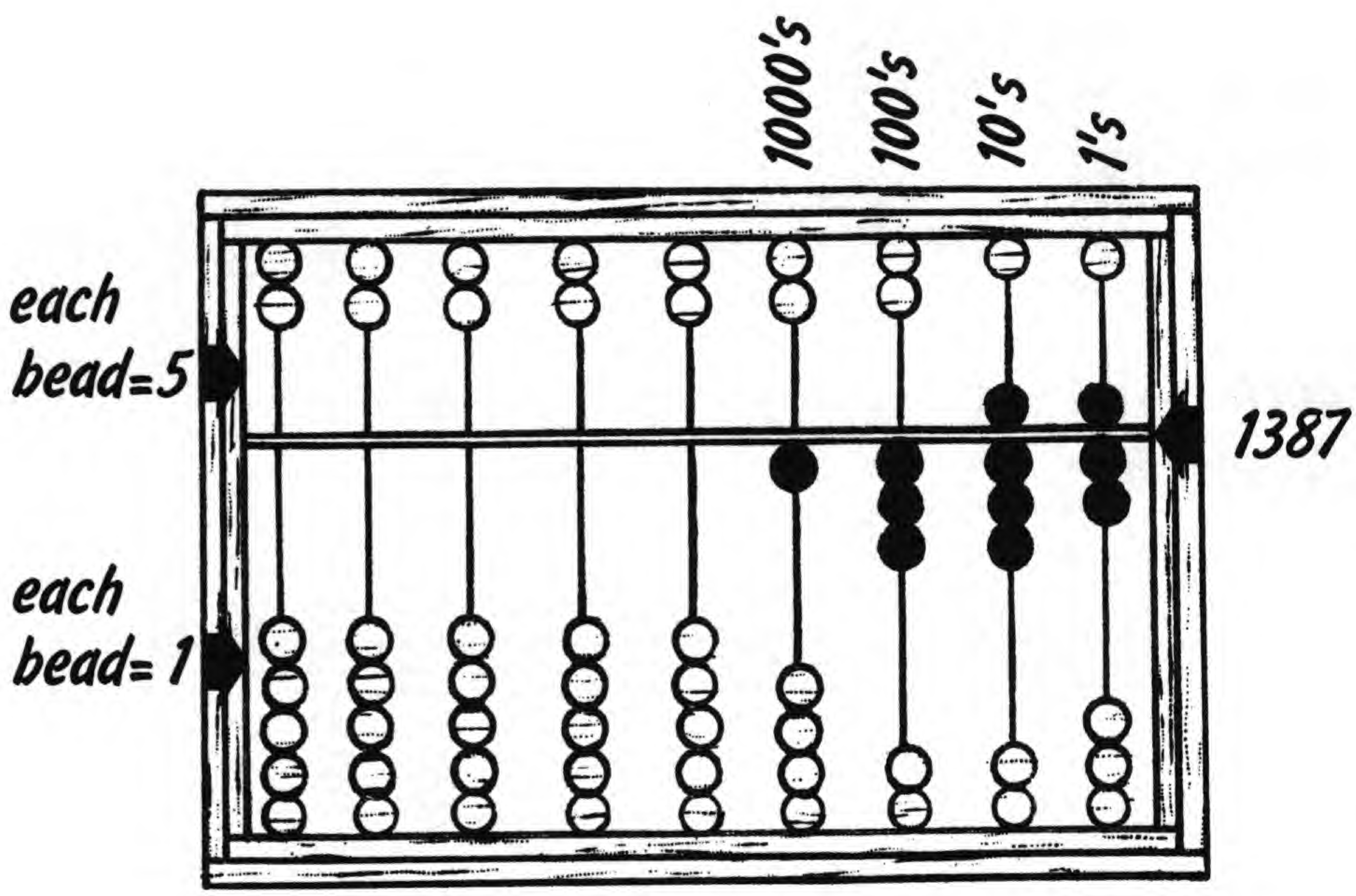


Fig. 23. Step-by-step calculating detail (half scale).

umn, three one-value and one five-value beads in the tens column, and two one-value and one five-value beads in the ones column, giving a total of 1387.

Now add the 32, beginning with the 3 in the second col-

umn from the right. This is done by moving down a second upper bead worth five and subtracting two lower beads. But the total in this column is now 11, so you carry over the first digit, just as you do in written mathematics. To do this, take away the two upper beads in the second column and add

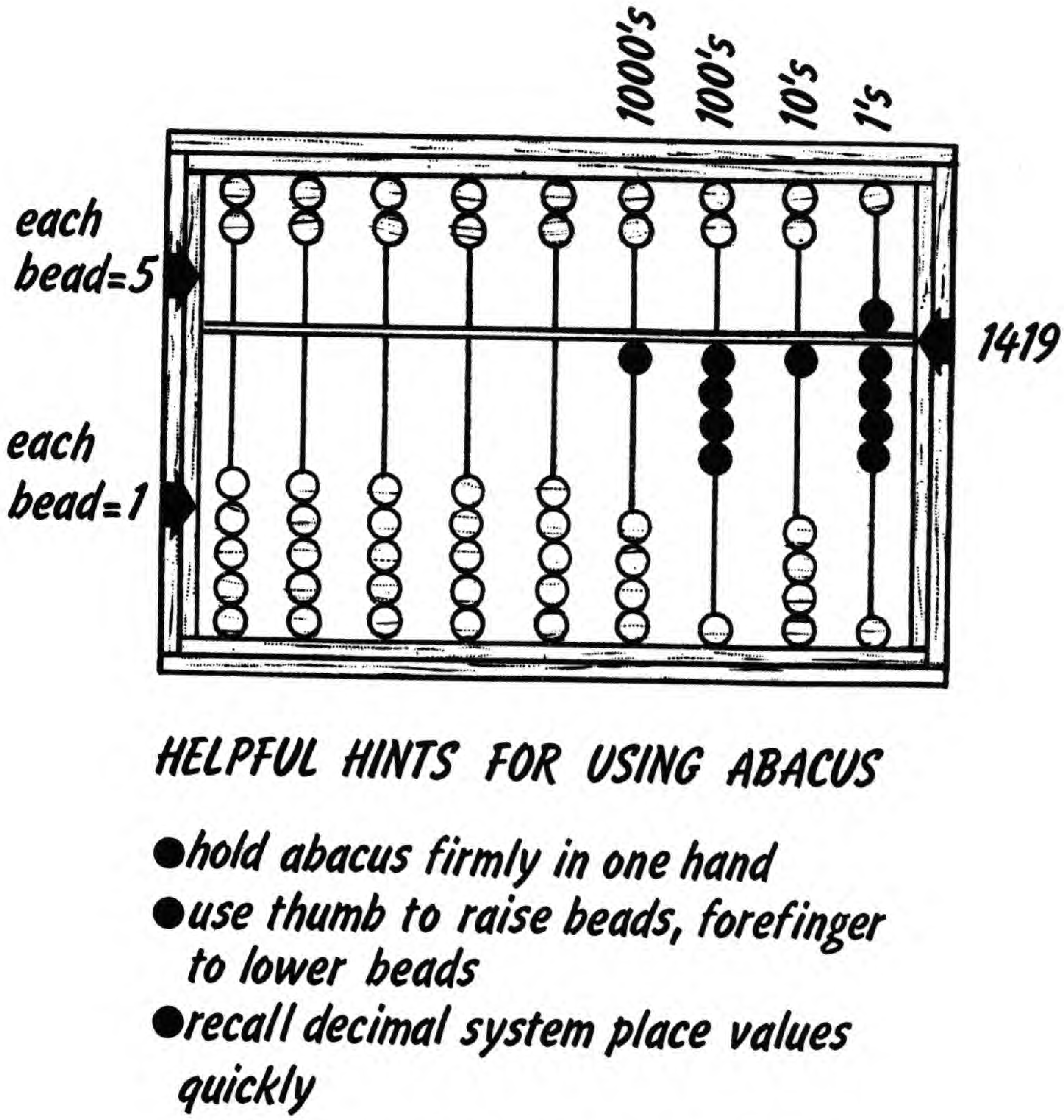


Fig. 24. Step-by-step calculating detail (half scale).

one of the lower beads to the third column. Now add the 2 to the right-hand column by moving up two more of the lower beads.

Counting the beads along the reading bar—remembering that the upper beads are worth 5 and the lower beads 1—you should get the number 1419, which is the total of 486 plus 901 plus 32. If you have any doubts about your results check them against Fig. 24.

Practice other problems. Remember you can do calculations on the abacus with answers that run into the millions! The abacus can also be used to work out problems in subtraction, multiplication, and division.

JOHN NAPIER'S "BONES"

John Napier, a Scottish mathematician who contributed a great deal to our present-day understanding of mathematics, developed a compact set of multiplication tables in 1580, when he was a young man of thirty. Instead of the hundreds of computing rods the Chinese, Koreans, and Japanese had needed, Napier's calculating device required only two rods.

Napier's two rods were called "bones" because he constructed them of ivory. Later models of the "bones" were carved out of wood.

To reconstruct this calculating device developed by Napier, you need the following:

MATERIALS

- 1/8″ thick x 2 1/4″ wide x 7 1/2″ long sheet of balsa or cigar-box wood
- 3/4″ thick x 3/4″ wide x 1 1/2″ long block of balsa or pine wood
- 3 pieces of 3/4″ x 3/4″ x 6 3/4″ balsa or pine wood
- Model airplane cement for wood
- Fine grade sandpaper
- Pen and India ink
- Transfer decal numbers (or pen and India ink can be used)
- Shellac

TOOLS

- Coping saw
- Brush for shellac
- Ruler

Saw all pieces of wood to the length and size given in the material list. Glue one of the 3/4″ x 3/4″ x 6 3/4″ pieces of wood to the left-hand side of the 1/8″ x 2 1/4″ x 7 1/2″ sheet of wood as shown in the drawing at the left in Fig. 25. Make sure the side and bottom edges of the block are flush with the backing sheet. Glue the 3/4″ x 3/4″ x 1 1/2″ block of wood along the bottom of the backing sheet, at right angles to the 6 3/4″ strip. This completes what is called the holder.

The two blocks of 3/4″ x 3/4″ x 6 3/4″ wood that remain are the two "bones." When the glue on the holder is dry, place these two blocks of wood in the holder (against the left-hand strip and the bottom strip) to make sure they fit properly. Sand the pieces of wood and apply one coat of shellac or clear model airplane dope to all surfaces.

Measure off 3/4″ squares on the table of multipliers—the bottom block—and the four sides of both bones. Rule these lines in with pen and India ink. Now draw diagonal lines from right to left in all the squares (except the top one) on all sides of the bones.

Referring to the tables for the bones (Fig. 26) write in or transfer decal numbers to all four sides of bone X and bone Y. If transfer decals are used, coat them with clear model airplane dope or nail polish.

Now refer to the full-scale calculating illustration (Fig. 27). Note that the upper left-hand triangles on the bones

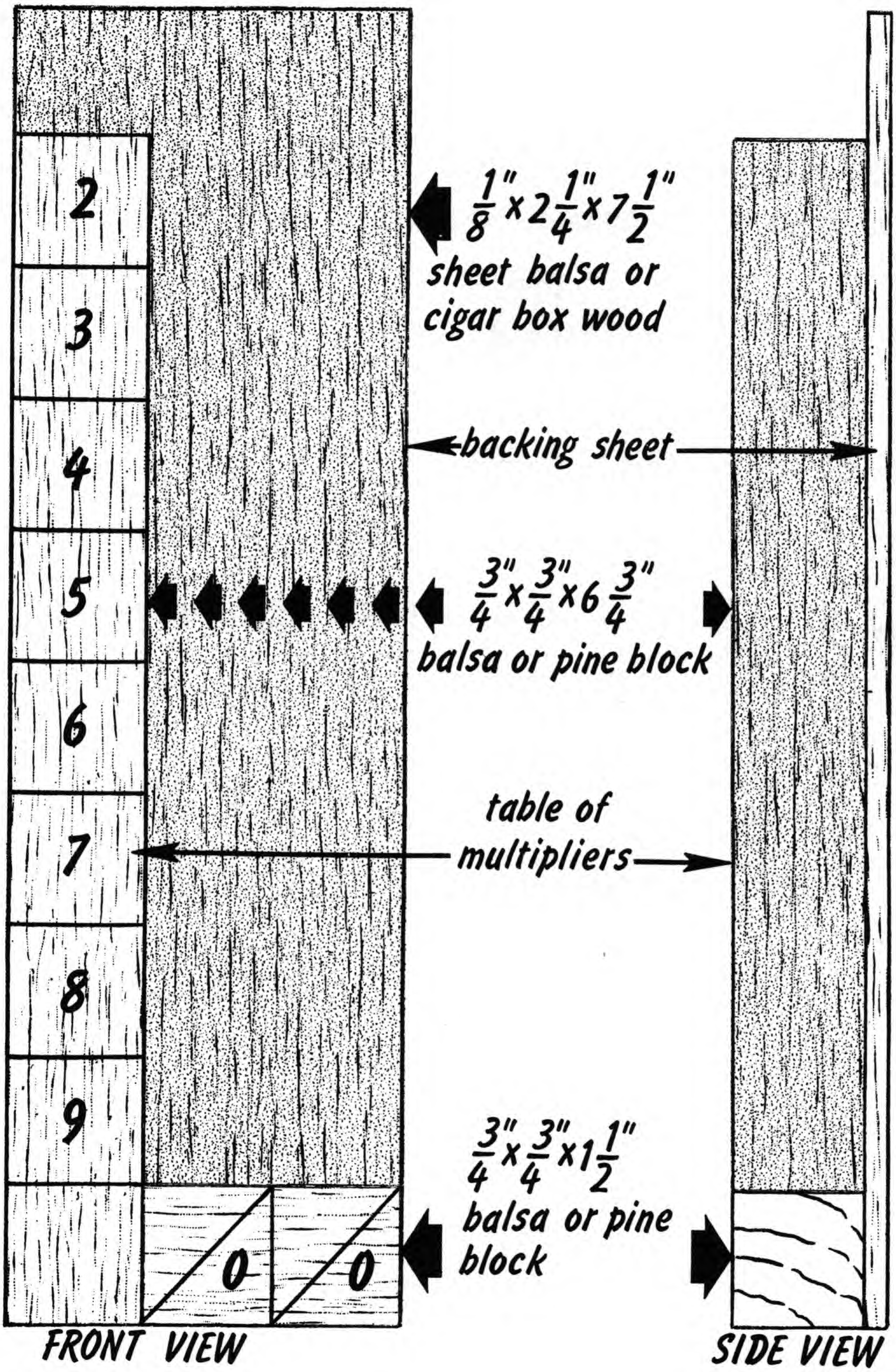


Fig. 25. Napier's "bones" (full scale).

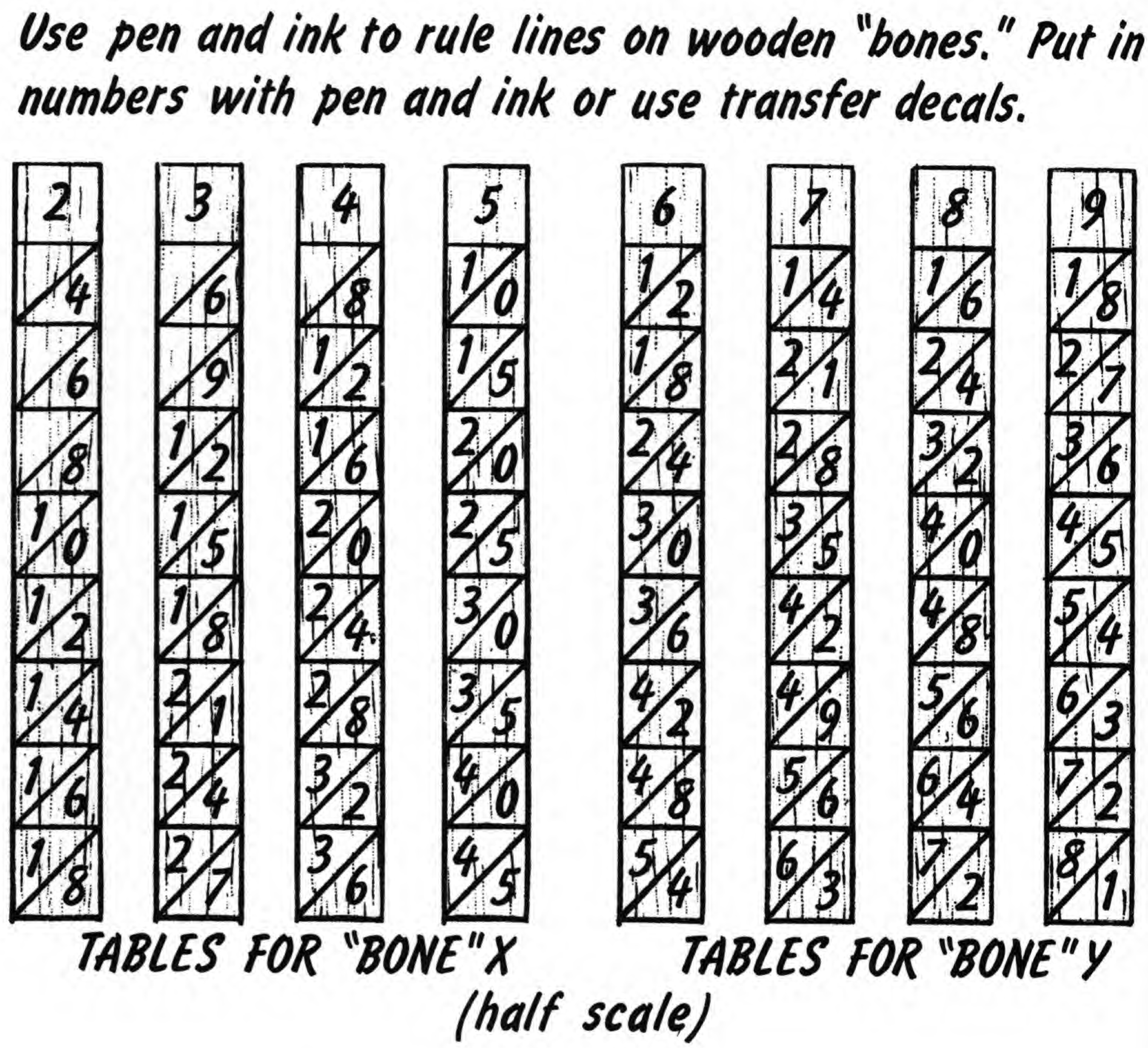


Fig. 26. Napier's tables for the "bones."

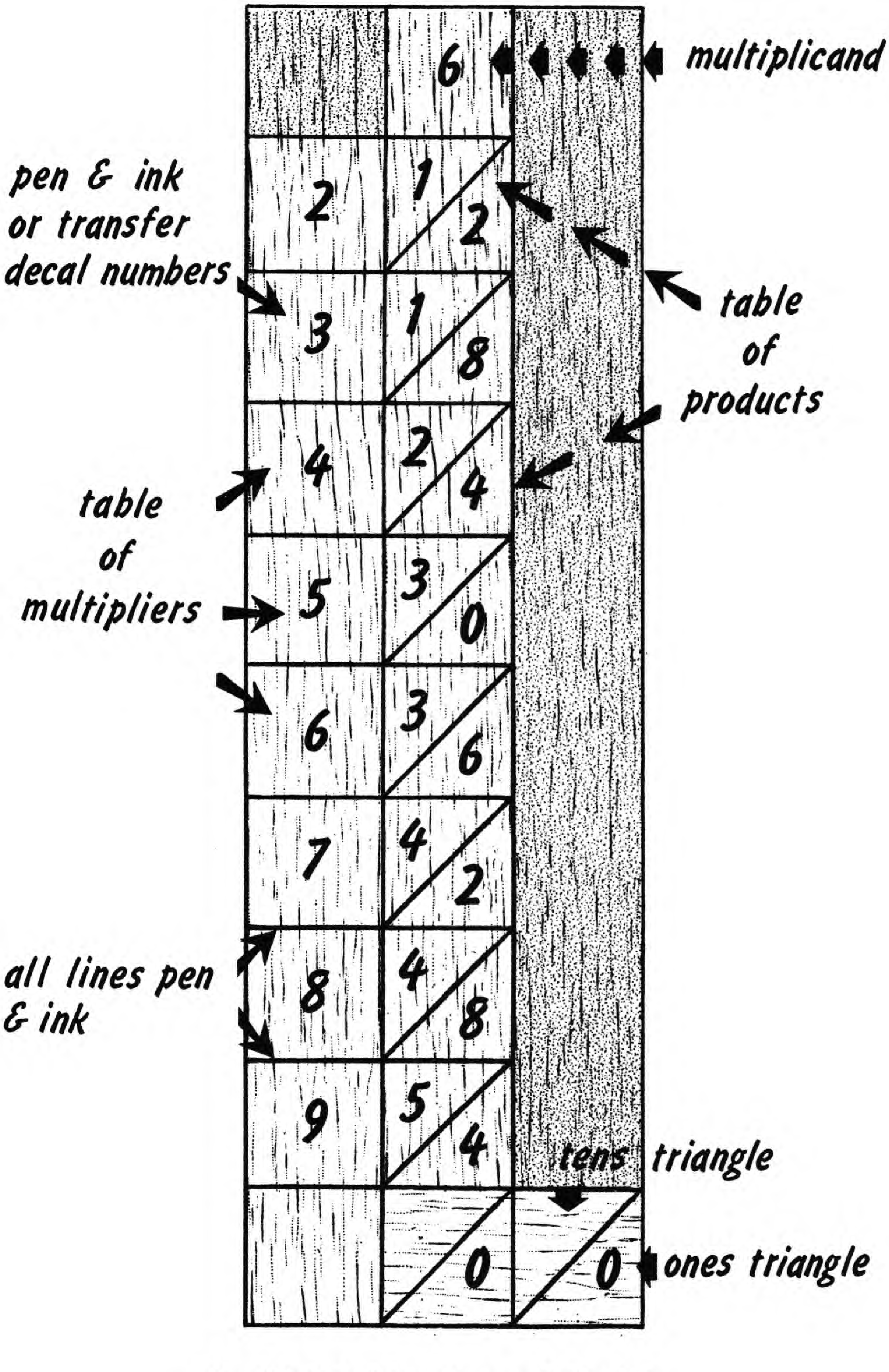


Fig. 27. Calculating diagram (full scale).

represent the tens column and the lower right-hand triangles represent the ones or units.

The whole numbers at the left represent the table of multipliers, the whole numbers at the top of the bones represent the multiplicand, and the squares with triangles represent the table of products or answers.

Let's multiply 4×6. Place the bone with the multiplicand 6 into the holder. Read horizontally across from the multiplier, 4, and the answer, 24, is found on the bone. Notice that 4×6 is really two tens and four ones or units.

Actually, Napier indicated through the use of these bones that multiplication is really a short cut to addition. In the problem 4×6 we are really adding 6 four times.

Napier's bones were not meant to solve complex problems, but they did help businessmen to carry on everyday transactions.

SLIDE RULES

After his development of portable multiplication tables John Napier continued his experiments to find more accurate and rapid ways of calculating. In 1614 he invented logarithms, which are the basis for all modern slide rules. The meaning of logarithms will become clear to you later, in your construction and use of sliding scales.

By 1620 Edmund Gunter, a British mathematician, had plotted Napier's logarithms on a two-foot straight line. Multiplication and division problems were calculated along this line through the use of a pair of dividers.

William Oughtred eliminated the use of the dividers in 1621 and found mathematical answers by sliding two of Gunter's straight lines by each other. But it was not until 1859 that Amédée Mannheim, a French army officer, perfected and constructed the slide rule that is used by today's scientists and mathematicians.

To fully understand how the slide rule works, secure the following:

MATERIALS

1/16″ x 2 1/2″ x 6″ flat strip of balsa wood

2 pieces of 1/16″ x 1/4″ x 6″ balsa wood

2 pieces of 1/16″ x 1/8″ x 6″ balsa wood

Four plastic 1″ x 6″ rulers (if different width rulers are used, adjustments will have to be made in the construction of the slide-rule holder)

- Model airplane cement for wood
- Fine-grade sandpaper
- White typing paper
- Pen and ink or transfer decal numbers
- Shellac, clear model airplane dope, or wax

TOOLS

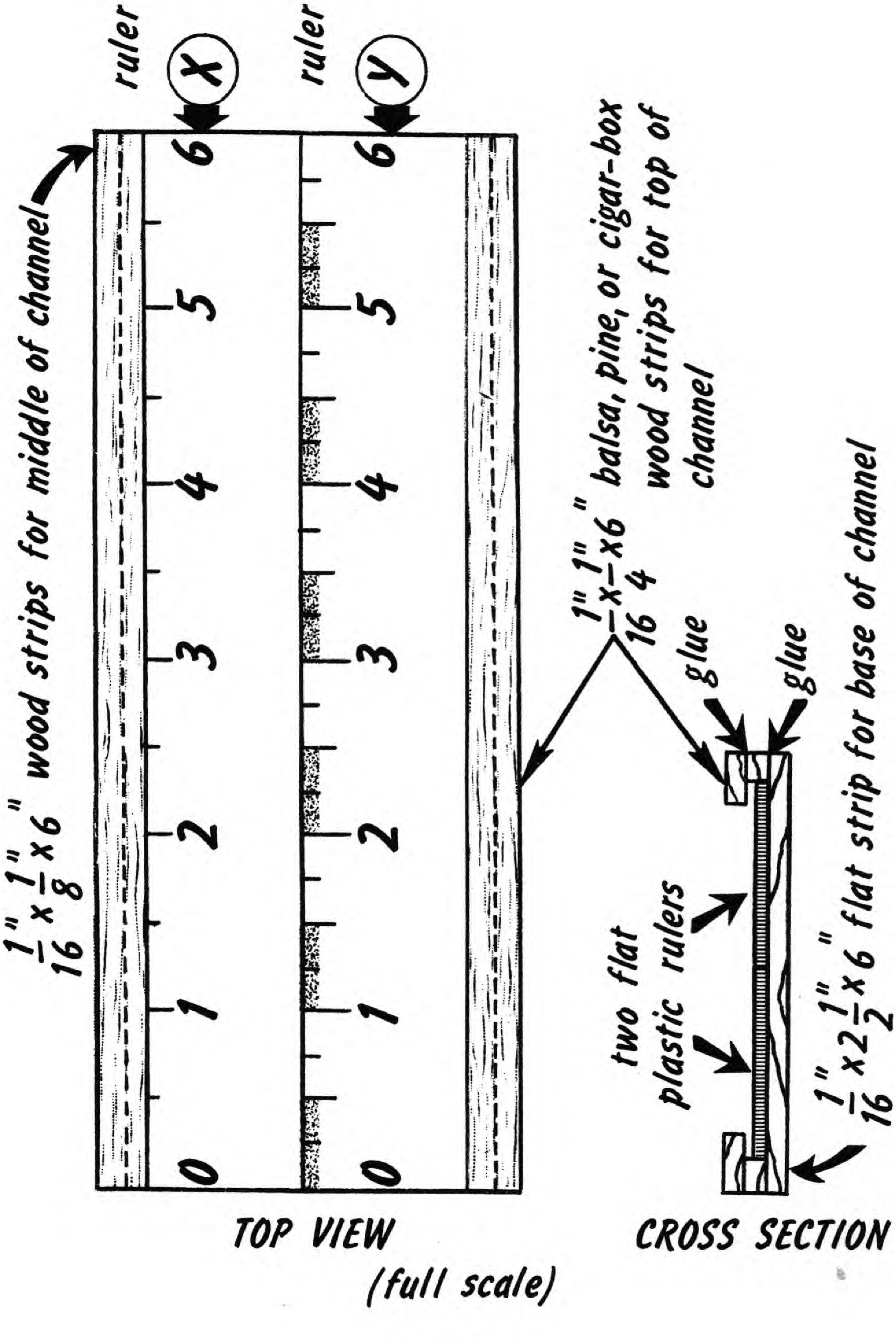
- Single-edge razor blade or X-Acto knife
- Brush

Glue the 1/16″ x 1/8″ x 6″ wood strips along the edges of one side of the 1/16″ x 2 1/2″ x 6″ flat strip. Make sure the edges are glued flush and even. On top of these two strips and flush with the outer edges glue the two 1/16″ x 1/4″ x 6″ strips of balsa wood. Refer to the full-scale top view and cross-section diagram (Fig. 28) to check your construction of the slide-rule holder. After sanding, shellac, dope, or wax the holder for ease in sliding the rulers.

Insert two plastic rulers into the channel from the end so that they slide easily by each other.

Now you are ready to calculate addition problems with the slide rule. Lay it next to the illustration in Fig. 29. To solve the problem $3 + 3 = ?$ slide ruler X to the right until the 0 on that ruler is directly over the line for the 3 on ruler Y. Following the line for the 3 on ruler X downward to the line underneath it on ruler Y, the answer 6 is found.

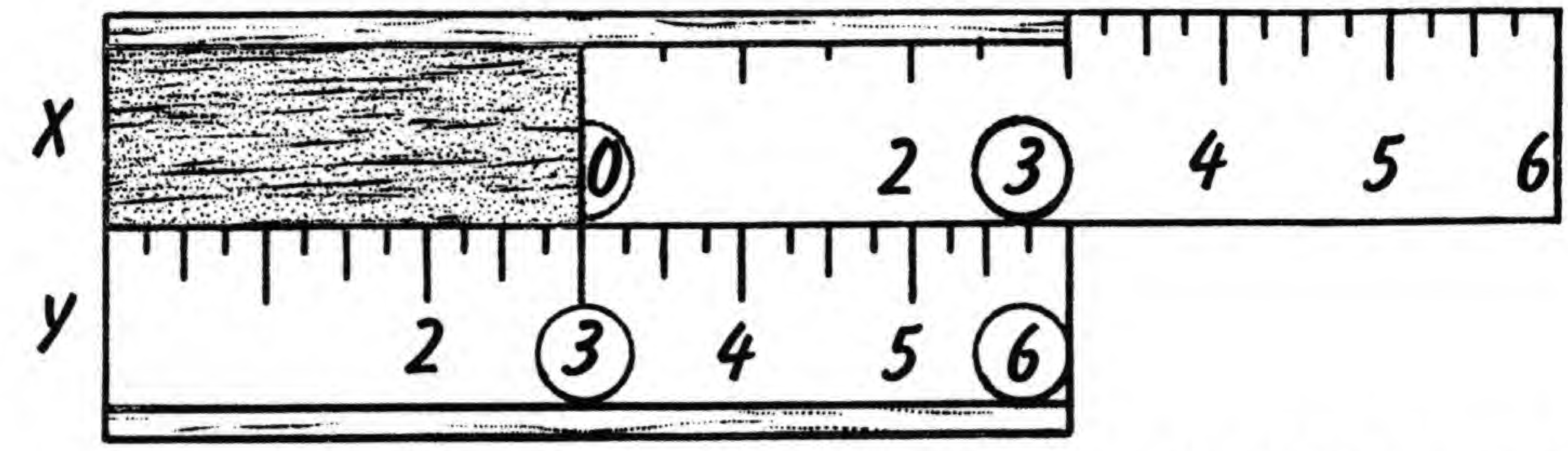
This slide rule can even add whole numbers with fractions. Using the same procedures, try the example in Fig. 29.



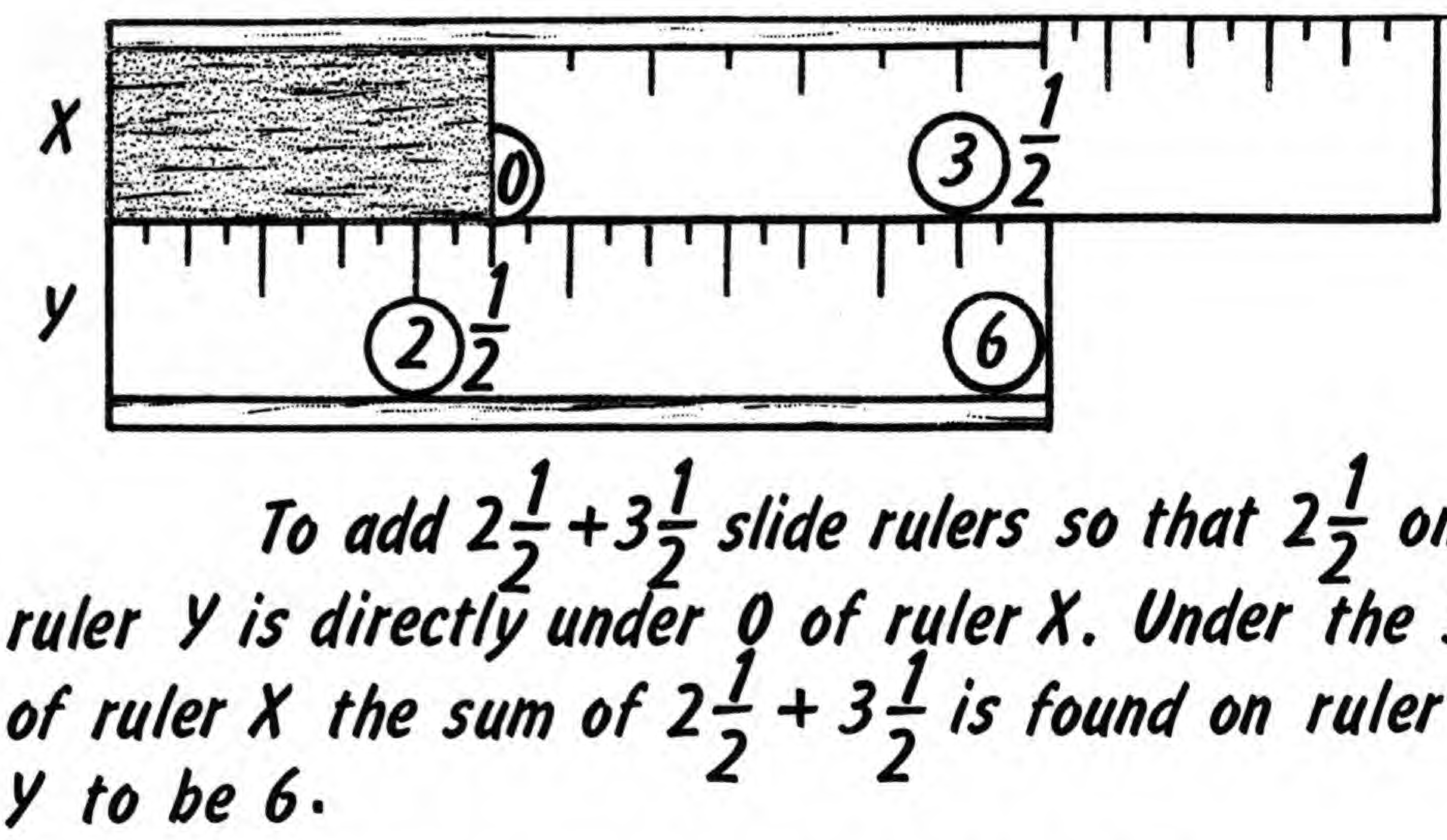
ruler
X
ruler
Y
1/16" x 1/8" x 6" wood strips for middle of channel
6
5
4
3
2
1
0
6
5
4
3
2
1
0
1/16" x 1/4" x 6" balsa, pine, or cigar-box wood strips for top of channel
glue
glue
two flat plastic rulers
1/16" x 2 1/2" x 6" flat strip for base of channel
TOP VIEW
(full scale)
CROSS SECTION

Fig. 28.

SLIDE RULE THAT ADDS
(half scale)



To add $3+3$ slide rulers so that 3 on ruler Y is directly under 0 of ruler X. Under 3 of ruler X the sum of $3+3$ is found on ruler Y to be 6.



To add $2\frac{1}{2}+3\frac{1}{2}$ slide rulers so that $2\frac{1}{2}$ on ruler Y is directly under 0 of ruler X. Under the $3\frac{1}{2}$ of ruler X the sum of $2\frac{1}{2}+3\frac{1}{2}$ is found on ruler Y to be 6.

SLIDE RULE THAT SUBTRACTS

Use the same ruler scales to subtract. Subtrahend (the number to be taken from another, the minuend) on ruler X is placed directly over minuend on ruler Y. Answer is found under 0 of ruler X on ruler Y.

Fig. 29. Adding and subtracting with the slide rule.

The same slide rule can also be used to subtract. Set down any subtraction problem that contains numbers from 1 to 6. (Since for this particular slide rule we are using a six-inch ruler, problems must be limited to those whose answers do not exceed six. The use of twelve- or eighteen-inch plastic rulers will extend the use of this slide rule as a calculating device.) The subtrahend (the number to be taken from another, called the minuend) on ruler X is placed directly over the minuend on ruler Y. The answer is found under the 0 line of ruler X on ruler Y.

To multiply with a slide rule, as William Oughtred did, we must change the inch scale on the rulers to a logarithmic scale. Let's follow Napier's development of logarithms to see why the change is needed.

Napier reasoned that writing $3 \times 3 \times 3 \times 3$ is really writing 3 four times. First he left out the times sign ($\times$) and used a dot ($\cdot$) in its place. Now the same multiplication problem reads $3 \cdot 3 \cdot 3 \cdot 3$. Then he shortened the problem to read 3^4, which shows that the three is to be multiplied by itself four times. Multiplying $3 \cdot 3 \cdot 3 \cdot 3$ or 3^4, he found the answer to be 81. Thus 3^4 is a new way of writing 81. Napier named the ^{4}, which told him how many 3's to multiply together to arrive at the answer 81, the logarithm of 81.

Carrying his experiments further, Napier reasoned that the logarithm of 9 is ^{2} and that $3^4 \cdot 3^2$ is really $3 \cdot 3 \cdot 3 \cdot 3 \cdot 3 \cdot 3$, which, when calculated, gives the answer 729. Therefore he

concluded that ^{6} is the logarithm of 729 and that the easiest way to write this number is 3^6.

In the process of experimenting with his new method of multiplication, Napier also noticed that when 81 (3^4) and 9 (3^2) were multiplied together to get 729, the 4 and 2 added together to make 6.

Utilizing Napier's experiments as a basis, Edmund Gunter plotted logarithms on a two-foot line. The distance of every number on this line from the end of the line was equal to the logarithm of the number. Although Gunter knew that adding logarithms was like multiplying numbers, he did not continue his experiments far enough to develop the slide rule. This was the work of William Oughtred, who knew of both Napier's and Gunter's experiments and used his knowledge of their work to develop the first such device.

First Oughtred drew two of Gunter's logarithmic scales on pieces of paper, then he slid these by each other so that the two scales added the logarithms. This, again, was like multiplying numbers.

Construct another slide-rule holder or use the same one you made for the slide rule that adds. Lay a sheet of white typing or tracing paper over the drawing of William Oughtred's sliding logarithm scales (Fig. 30). Trace these two scales accurately, using pen and India ink. Draw in or put transfer decal numbers on the scales, and then rubber cement these scales to two plastic rulers. The sliding logarithm scales are now ready for use.

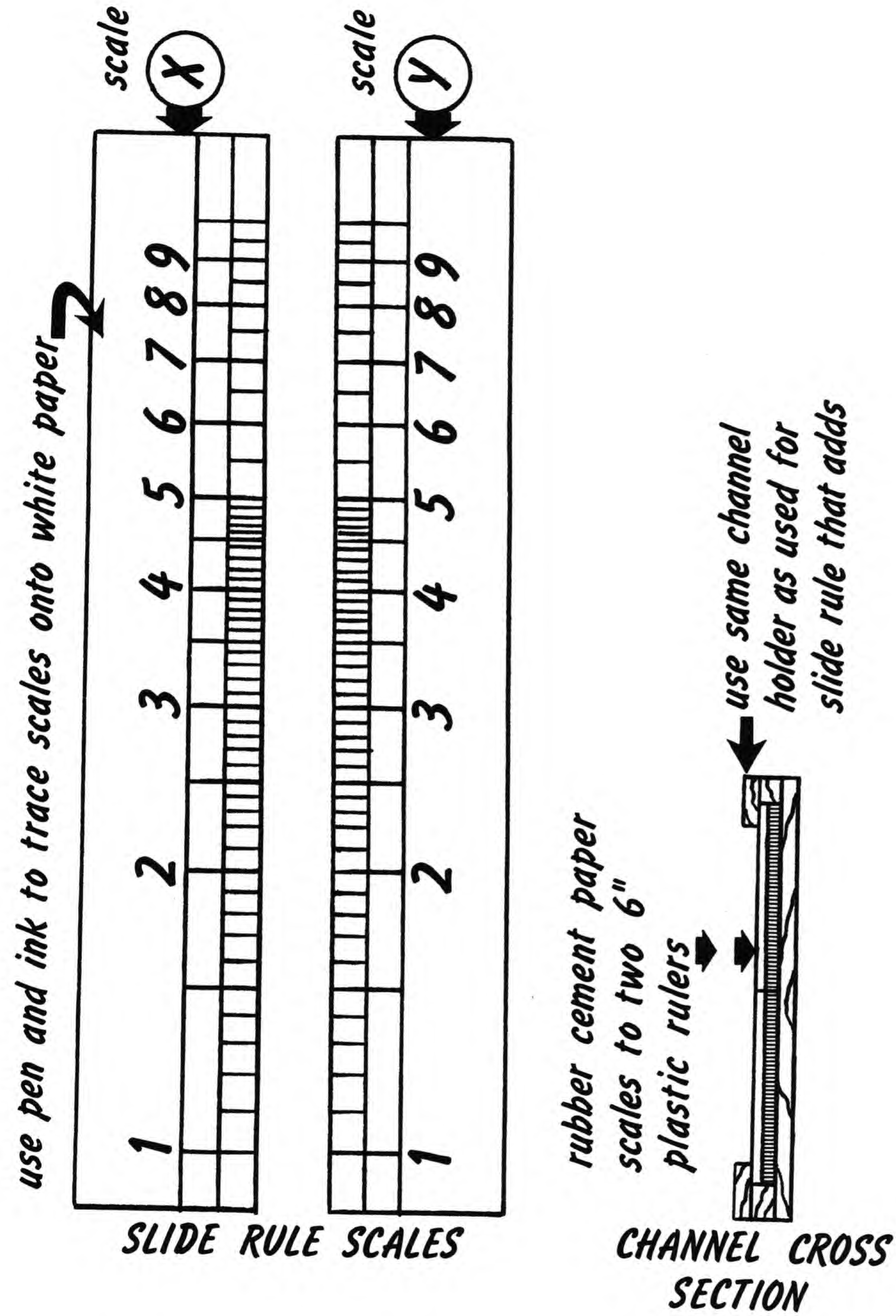


Fig. 30. William Oughtred's sliding logarithm scales (full scale).

Try multiplying 2 × 4. Set the 2 (multiplier) on scale Y so that it lines up with the 1 on the top scale, X. Read across scale X until you come to the 4 (multiplicand). Directly under the 4 but on scale Y the answer 8 is found.

Look at the scales again and notice that the distance of each number symbol from the end of the scale has been worked out to be equal to the logarithm of the number.

"STEPPED-WHEEL" CALCULATOR OR ODOMETER

Many counting machines, desk calculators, adding machines, and odometers are based on the principles developed by Pascal, Leibnitz, and Thomas. Blaise Pascal built a simple calculating machine which consisted of a series of wheels that would add and carry 10's. By 1671 Gottfried von Leibnitz improved on Pascal's computer. Knowing that multiplication was a shorter way of doing addition he developed a machine that repeated the process of addition rapidly and so could solve multiplication problems. Charles Xavier Thomas then used both Pascal's and Leibnitz's inventions to develop the first automatic desk calculator, which was first demonstrated in 1820.

Since that time most desk-type calculators have used the principle of counting numbers through a series of moving wheels. Construct your own wheeled calculator or odometer as follows:

MATERIALS

- 3″ length of 1/4″ in diameter wooden dowel
- 1 3/4″ x 5 1/4″ piece of cigar-box, pine, or balsa wood
- A size 60 thread spool
- Box of 18 gauge 1/2″ long wire nails
- Glue
- Pen and India ink or transfer decal numbers
- 8 cardboard or metal washers to fit dowel
- White typing paper
- Carbon paper

TOOLS

Coping saw	Hammer
Needle-nose pliers with side cutters	Hand drill
	1/4″ and 3/8″ bits

To begin, trace the full-scale front view of the "stepped-wheel" calculator holder (Fig. 31) onto white typing paper and then retrace this onto the 1 3/4″ x 5 1/4″ piece of wood. Drill the window and axle holes. Saw the wooden dowel into four 3/4″ lengths for the wheel axles. Glue the axles into the 1/4″ holes, making sure the axles are at right angles to the holder board.

Now saw four 3/8″ thick wheels from the thread spool. Trace onto white paper the gear-teeth pattern shown in Fig. 32 and transfer it to one side of each wheel. Following the lines of the pattern and the bottom drawing in Fig. 32, carefully hammer ten nails into wheels D, C, and B 1/8″ from the outside diameter. Drive one nail into wheel A. Hammer the nails about halfway through each wheel.

Using the needle-nose pliers, bend one nail on wheels C and B and the one nail on A into L-shapes to form engaging teeth. When the calculator is assembled, wheel A will turn wheel B, wheel B will turn wheel C, and wheel C will turn wheel D. Note in Fig. 32 that the engaging tooth on each of the wheels is bent at a different height, to insure that they pass by one another, turning only one number as they engage. Cut the heads off these nails with the side cutters.

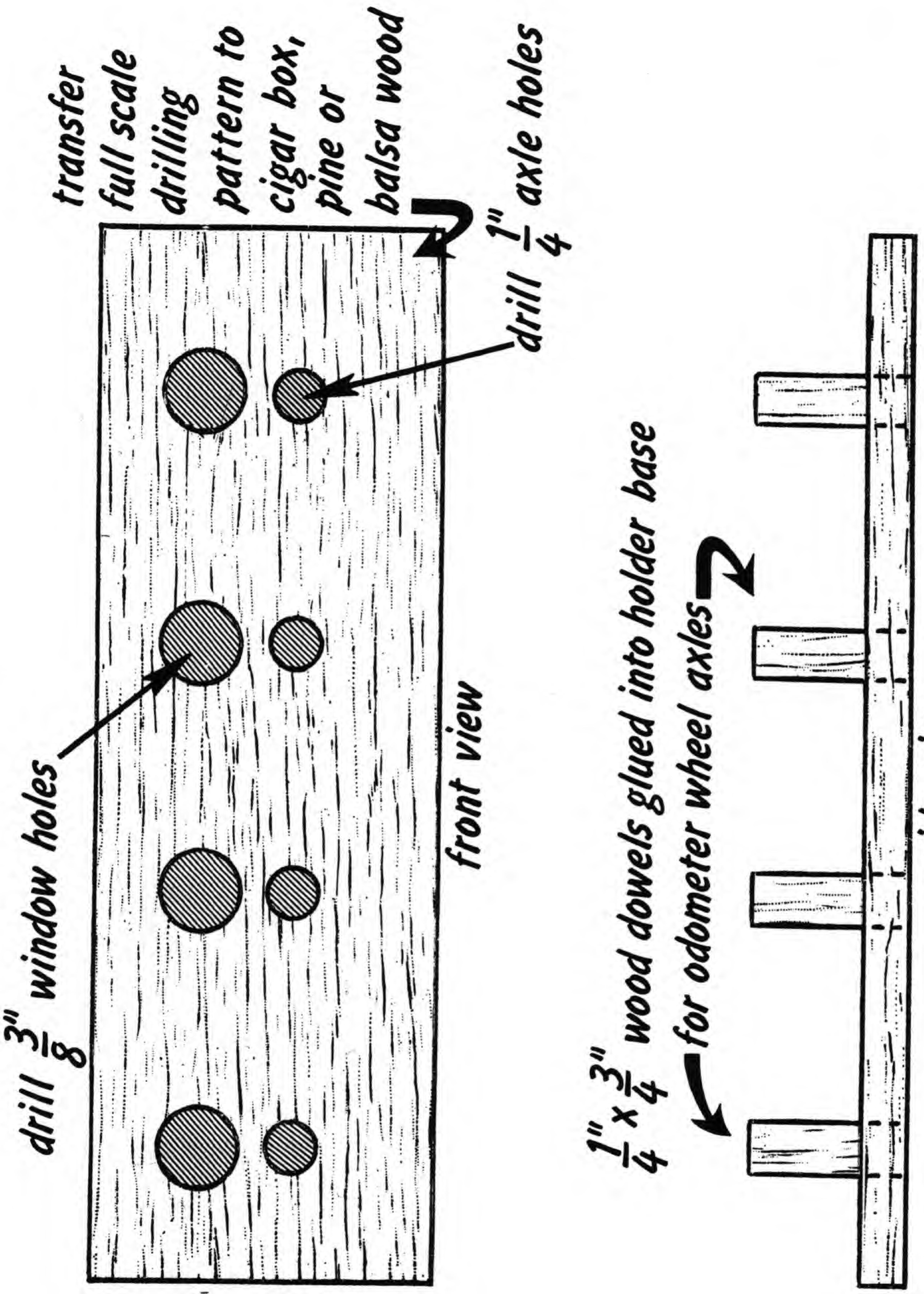


Fig. 31. "Stepped-wheel" calculator holder (full scale).

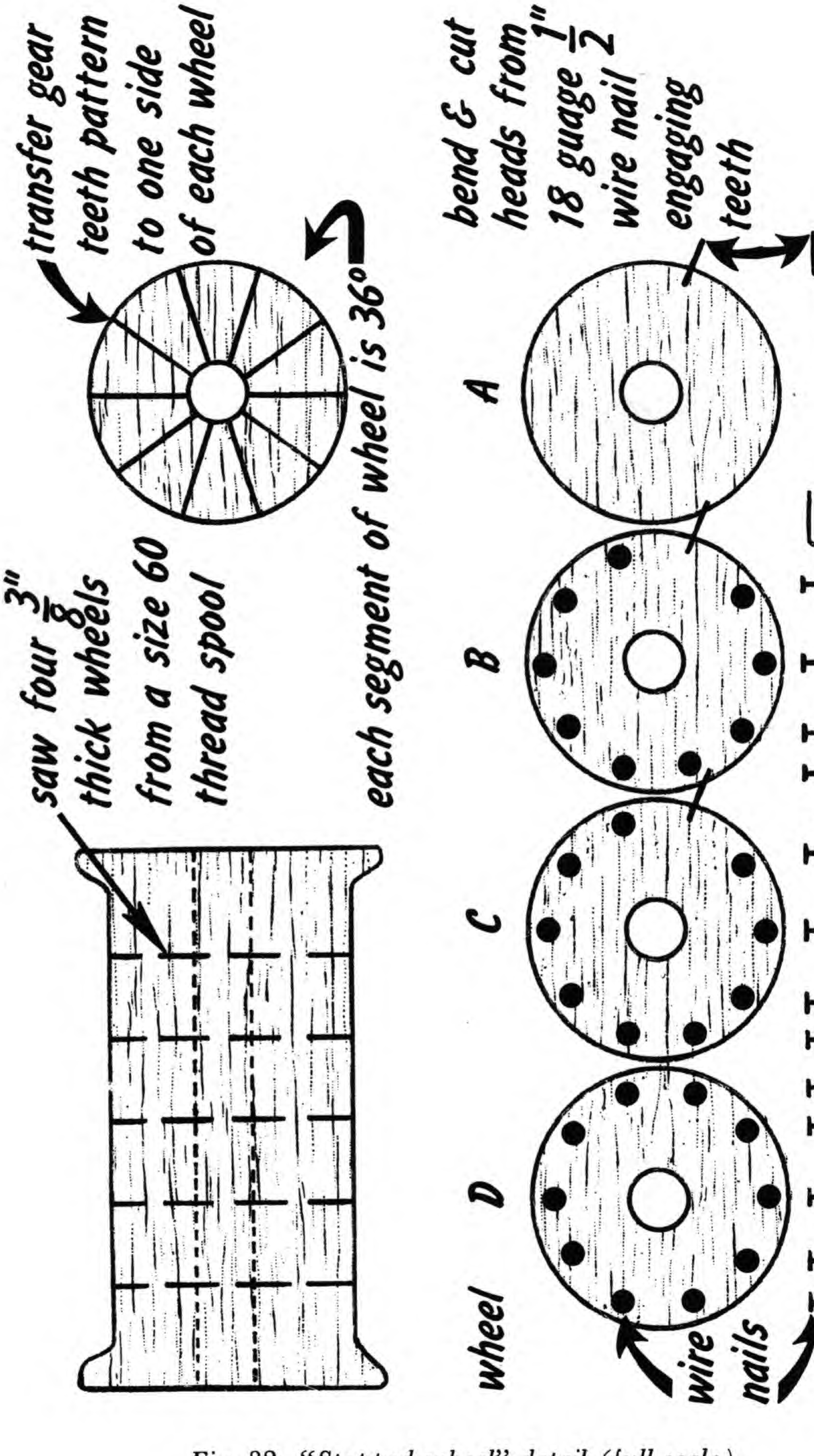


Fig. 32. "Stepped-wheel" detail (full scale).

Slip one washer onto each of the axles and place the wheels on the axles in the order shown in Fig. 33. Put another washer over each wheel and glue this one to the axle, allowing the wheel to move without a great deal of friction.

To finish the "stepped-wheel" calculator you must put decal numbers from 0–9 on the wheels so that they show through the windows. Each number has to be carefully placed in its proper position on each wheel to insure that the wheels engage one another at the proper point. The numbers are placed in the following manner:

Fig. 32 shows that each wheel is divided into ten segments. First, set wheel A's engaging tooth so that it meets or engages wheel B's engaging tooth. Turning wheel A in a clockwise direction from the back of the holder, place the numbers from 0–9 in each one of the segments as they appear in wheel A's window.

Next, set wheel A and wheel B's engaging teeth so that they again engage each other. A zero should appear in the window of wheel A. At this point place a 0 in wheel B's window. Turn wheel A one complete clockwise revolution until its engaging tooth engages one of the gear nails on wheel B and turns it one segment. Place the number 1 in wheel B's window. Continue to turn wheel A until it has engaged each gear tooth on wheel B and the numbers 0 to 9 have been placed on wheel B. Note that while wheel A travels in a clockwise direction, wheel B travels in a counterclockwise direction.

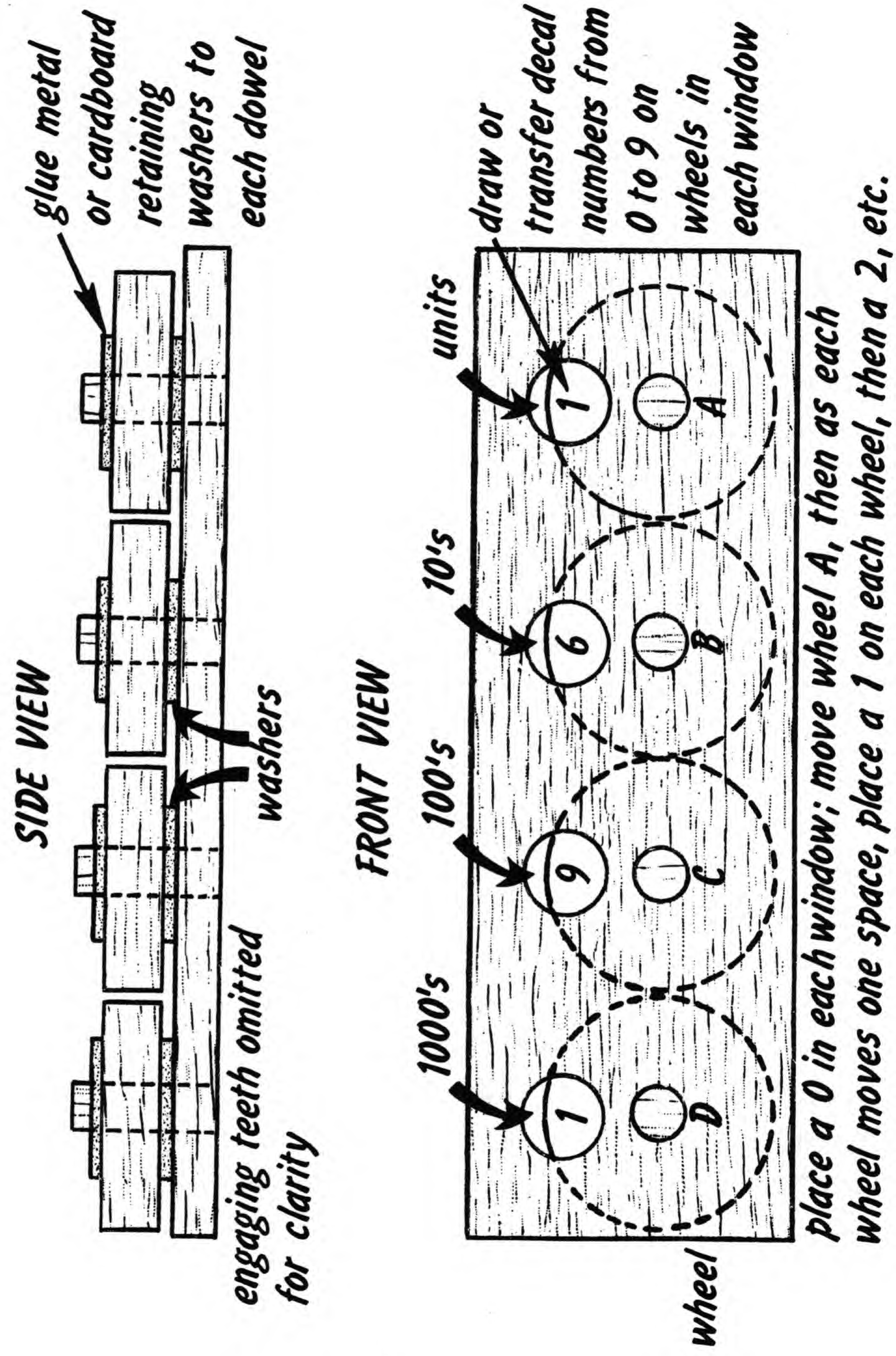


Fig. 33. "Stepped-wheel" calculator assembly (full scale).

Now turn wheel A until the number 0 appears in the window of both wheel A and wheel B. Wheel B should now be engaging wheel C. Place a 0 in the segment of wheel C that appears in the window. Continue to turn wheel A until it has engaged wheel B enough times to move wheel C another segment. Place the number 1 in the window of wheel C. Continue this process until wheel C is numbered from 0 through 9.

Next set wheels A, B, and C so that each reads 0 in their respective windows. Place a 0 in the window of wheel D. Now follow the same process for numbering wheel D as you did for wheel C. Notice that wheel A turns clockwise, wheel B turns counterclockwise, wheel C clockwise, and wheel D counterclockwise.

You can see in Fig. 33 that wheel A measures units, wheel B tens, wheel C hundreds, and wheel D thousands on your "stepped-wheel" calculator. When wheel A turns from 9 to 0, wheel B turns to 1. After wheel B has turned ten spaces it engages wheel C and turns it once. And when wheel C has moved ten spaces, it in turn engages wheel D and turns it once. Earlier in the book it was explained that the odometer works on much the same principle.

Today's simple counting machines work on this same "stepped-wheel" principle too. When one wheel finishes counting, another continues. This is much like counting on your fingers.

These wheeled calculators also multiply by adding rapidly. To multiply 4 × 7 they merely add 7, 7, 7, and 7.

DIGITAL COMPUTER

In 1939 International Business Machines and H. H. Aiken, a scientist at Harvard, started work at that university on what was to become known as the first automatic-sequence-controlled calculator, or what we now call a digital computer. Work on the automatic calculator was finished in 1944. Since then many other computers have been constructed that can handle more problems more rapidly. These, of course, are huge and immensely complex machines, but you can build a very simple digital computer by following these directions:

MATERIALS

- Wooden cigar box about 7″ x 8 1/2″ or larger
- Two 1″ x 4″ pieces of cigar-box wood or other thin wood
- Two coils of connecting wire (one color for one switch, another color for the other switch)
- Seven miniature flashlight bulbs
- 42 large-headed brass paper fasteners or 42 1/8″ x 3/8″ brass nuts and bolts
- Tin coffee can
- 1/2″ long rectangular-headed brass paper fasteners
- Pen and ink or transfer decal numbers
- Model airplane double battery holder
- Two 1 1/2 volt flashlight cells, size D
- Screen-door handle
- Two 1/8″ x 3/4″ bolts with nuts and six washers to fit

Model airplane glue for wood	Typing paper
	Carbon paper

TOOLS

Hand or power drill	Coping saw
3/8″ bit and 1/8″ bit	Tin snips
Needle-nosed pliers with side cutters	Screwdriver
	Scissors

First, place a sheet of typing or tracing paper over the full-scale layout for the holes that must be drilled in the top of the cigar box (Fig. 34), and carefully trace the holes for the flashlight bulbs and terminals. Trace these in turn onto the top of the cigar box. Drill 3/8″ holes for the flashlight bulbs and 1/8″ holes for the terminals. Now open the cigar box so that the inside of the cover faces you (Fig. 35). Pencil in letters of the alphabet as shown in Fig. 35 so that you can identify the terminals when you are wiring the computer.

Following the bulb-mounting detail in Fig. 35, insert the flashlight bulbs through the top of the cover and glue them in place. Make sure the tips at the base of the bulbs are in a straight line to insure good connections.

Now you have a choice. You can use large-headed brass paper fasteners or 3/8″ bolts and nuts for the terminals. If you use paper fasteners, insert them through the top of the cover and spread the ends to a Y-shape to hold them tempo-

holes y and z drilled for switch bolts

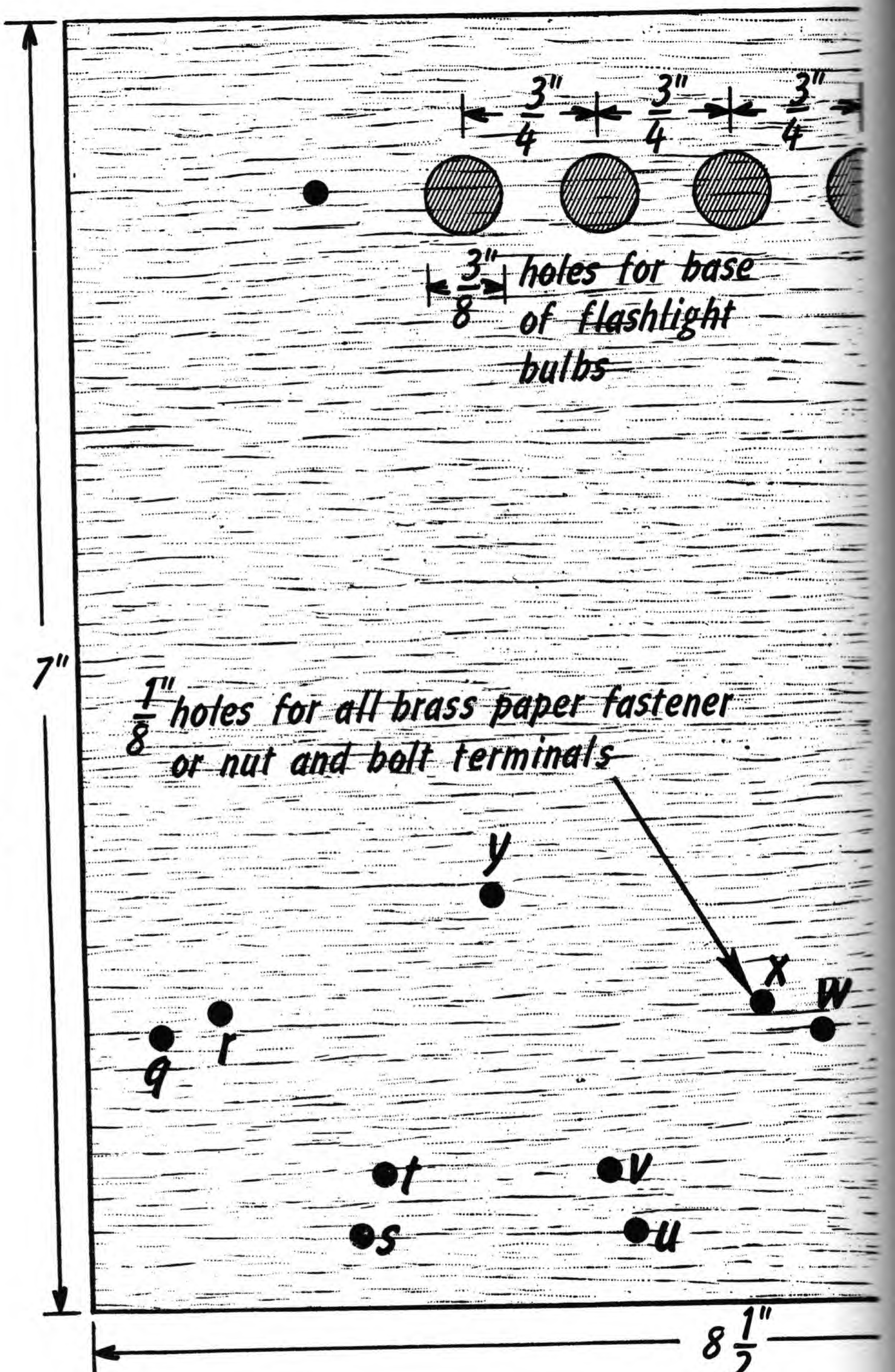
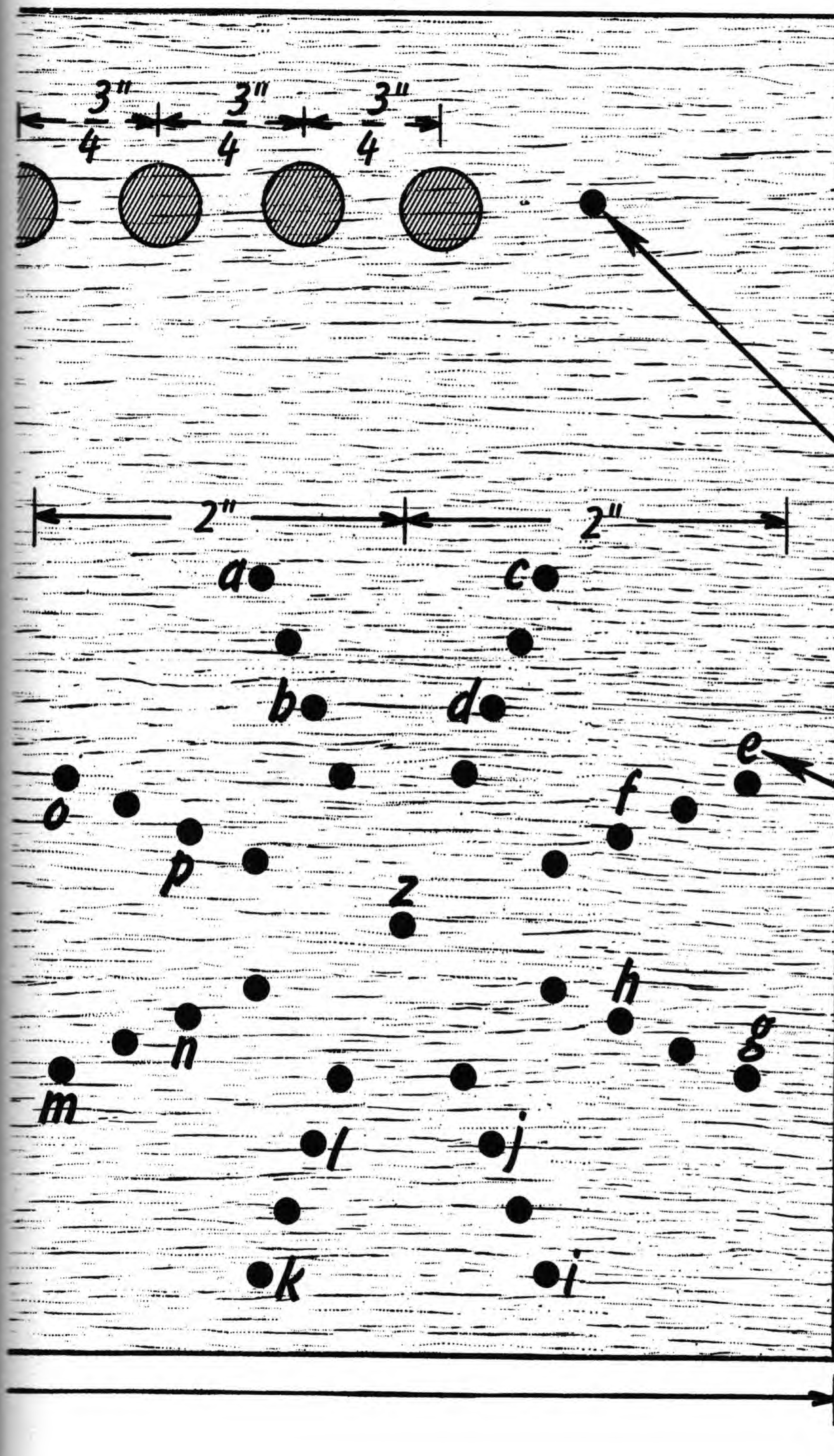


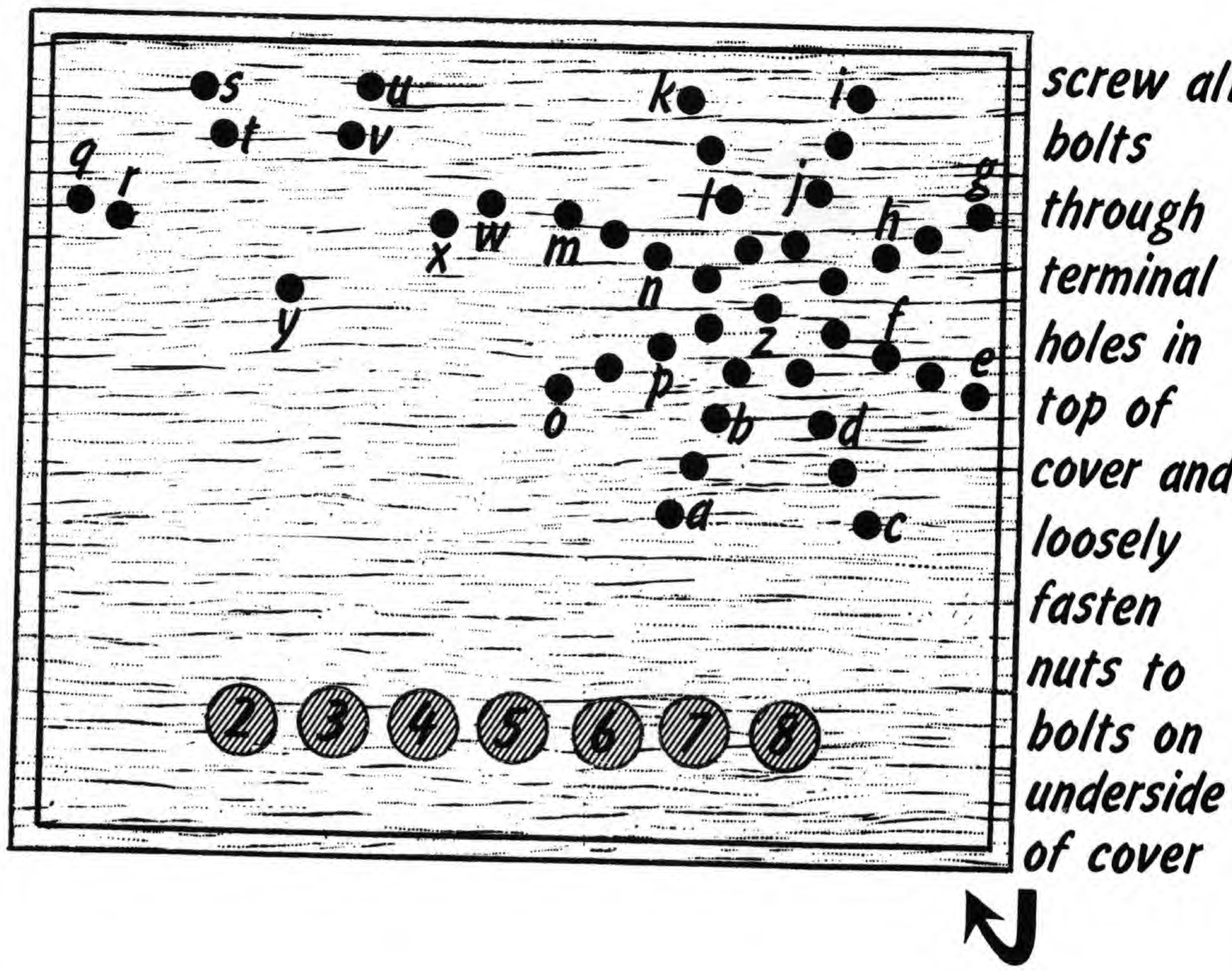
Fig. 34. Layout for drilling holes in top of cigar-box cover (full scale).



accurately trace shaded and solid circles onto thin white paper and transfer drilling pattern to top of cigar box

$\frac{1}{8}$" holes for bulb-base connections

letters identify terminals when wiring computer



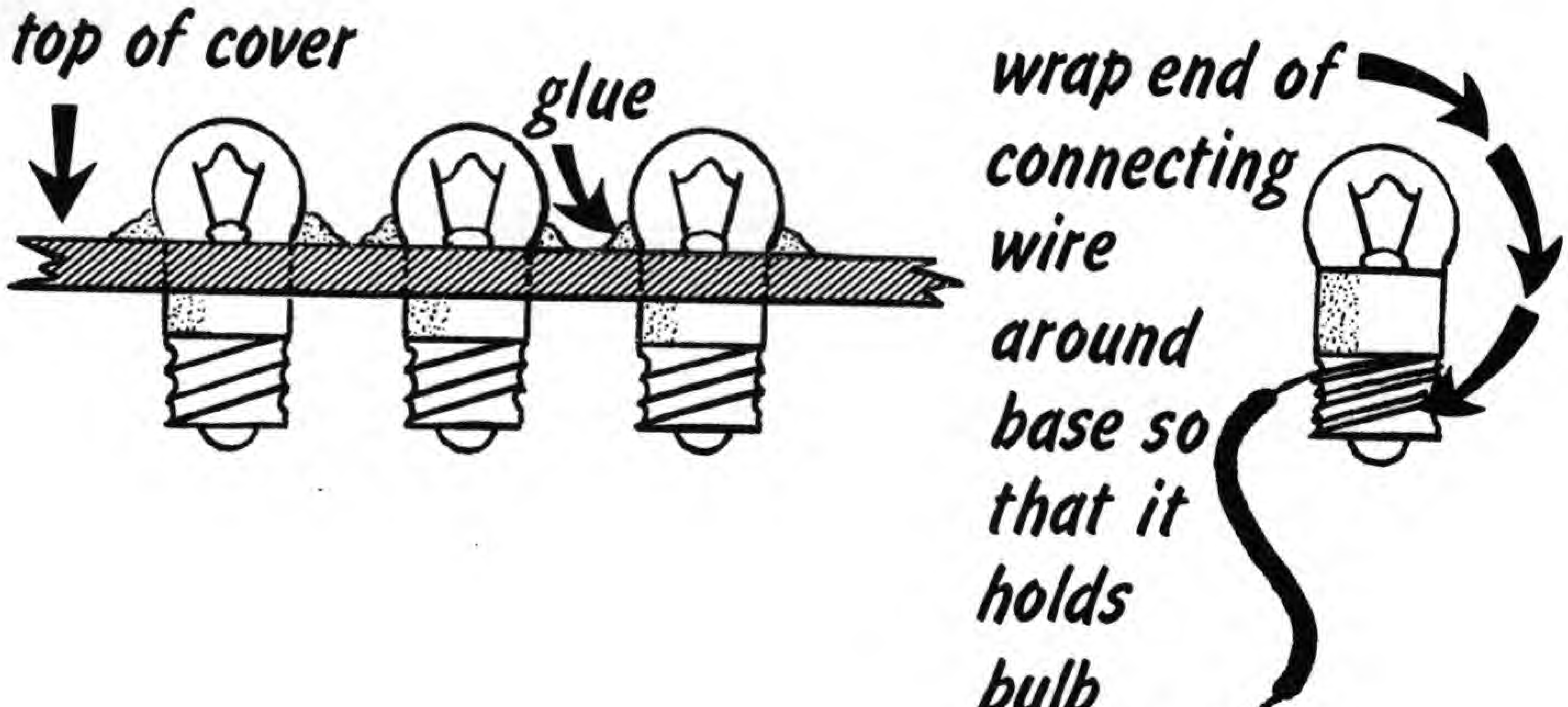


Fig. 35. Top: Underside of cigar-box cover showing placement of holes for terminals and flashlight bulbs (half scale). Bottom: Bulb mounting and wiring detail (full scale).

rarily in place. If you use bolts and nuts, screw all the bolts through the terminal holes in the top of the cover and loosely fasten nuts to the ends of the bolts.

You are now ready to start wiring the calculator. Note that all wiring is done on the underside of the lid. Using one color of connecting wire, cut the wires to connect the terminals for switch Z. Each piece of wire should be 1 1/2″ longer than the distance between the terminal points it is to connect. Remove 3/4″ of the insulation from the ends of each wire.

The next step is to wire switch Z, following the half-scale wiring plans shown in Figs. 36 and 37. In making the terminal-point connections be sure the wire is free of insulation and is firmly wrapped around the paper fastener or bolt. In attaching the wires to the ends of the bulbs, wrap them around the screw threads so that they are securely connected.

When you have finished making all the connections, check your work against the diagram shown in Fig. 38. If your wiring layout checks with the diagram, tighten nuts or bend the paper fasteners firmly against the wire connections.

Now, using the other color wire, start wiring switch Y, following the step-by-step wiring plans given in Figs. 39 and 40 and at the top of Fig. 41. In doing the wiring shown in Fig. 39 leave at least one foot of wire to make the connection to the battery holder. This will allow for opening and closing the box cover.

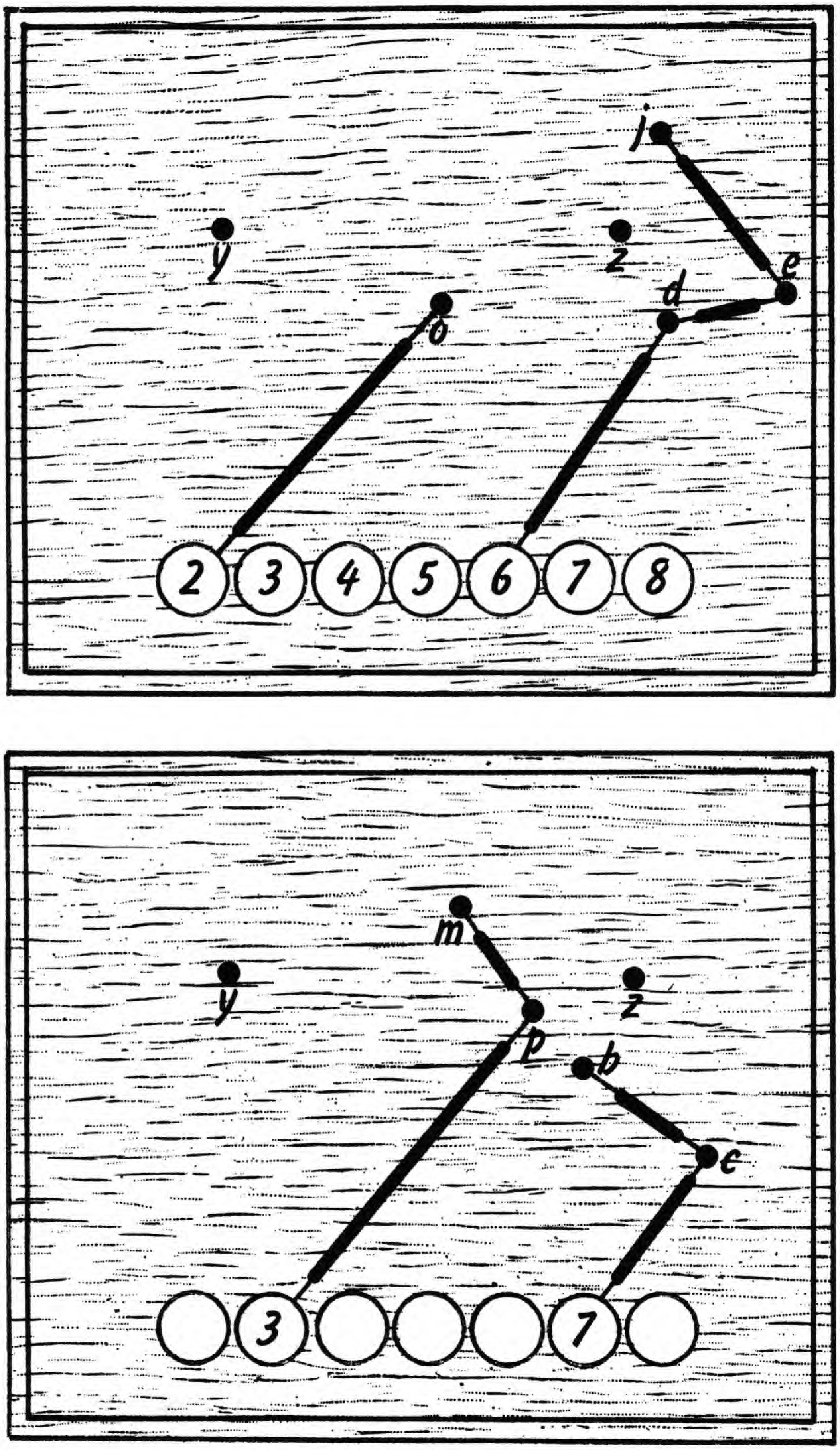


Fig. 36. Step-by-step wiring plans for switch Z (half scale). The numbered circles in the top drawing identify the bases of the flashlight bulbs for wiring connections.

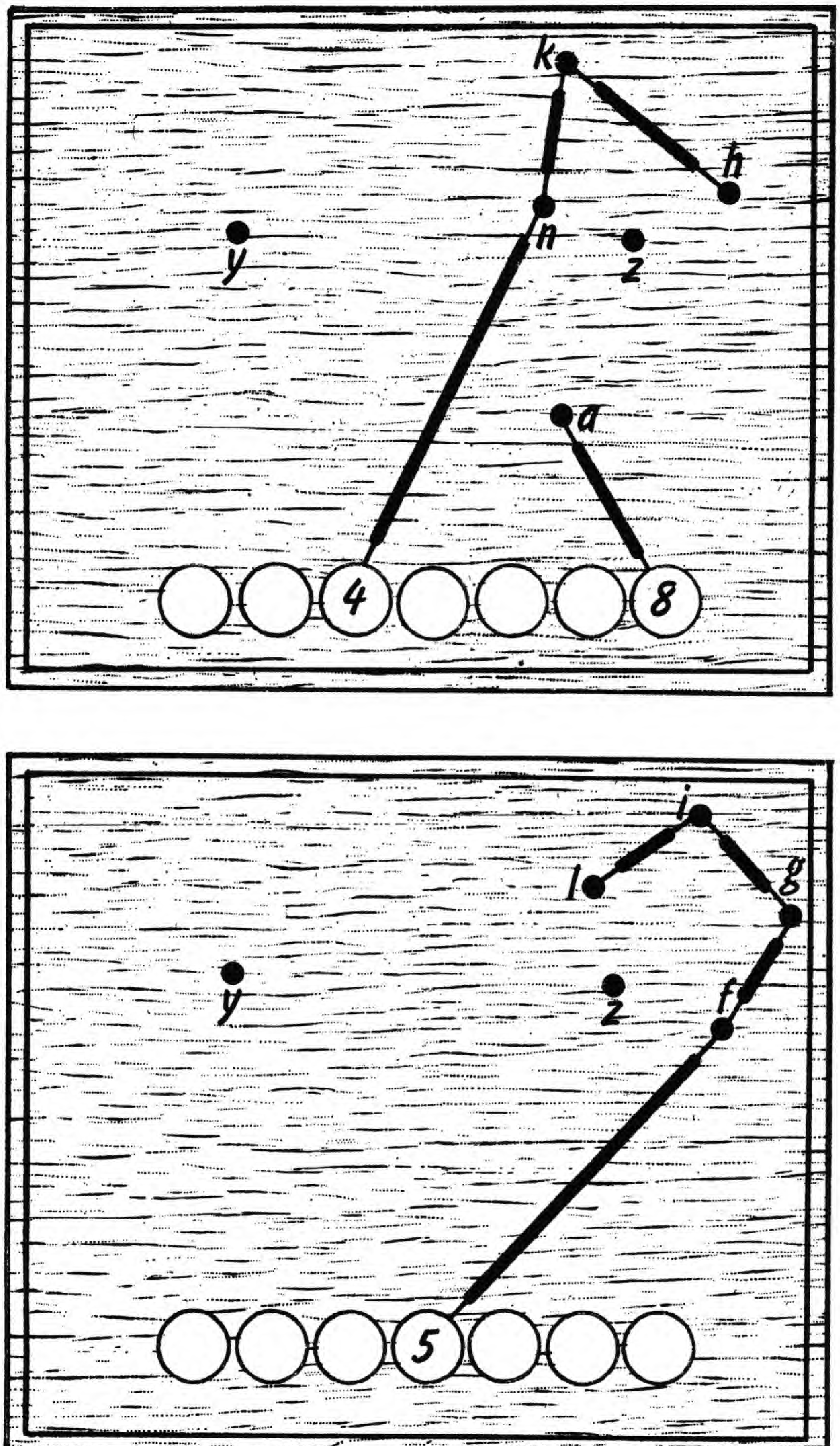


Fig. 37. Step-by-step wiring plans for switch Z continued.

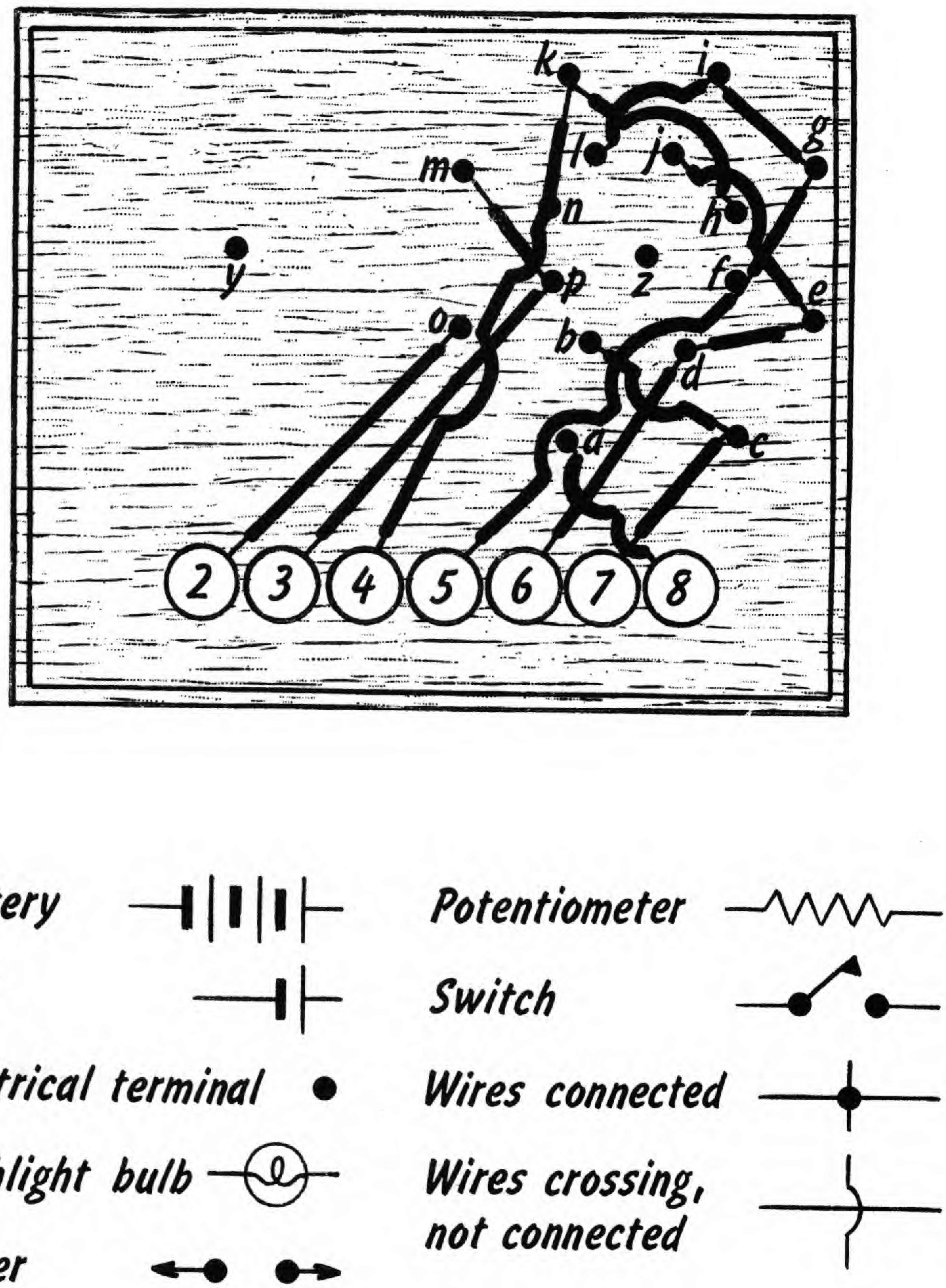


Fig. 38. Top: Completed wiring diagram for switch Z. Bottom: Common symbols used in electrical diagrams.

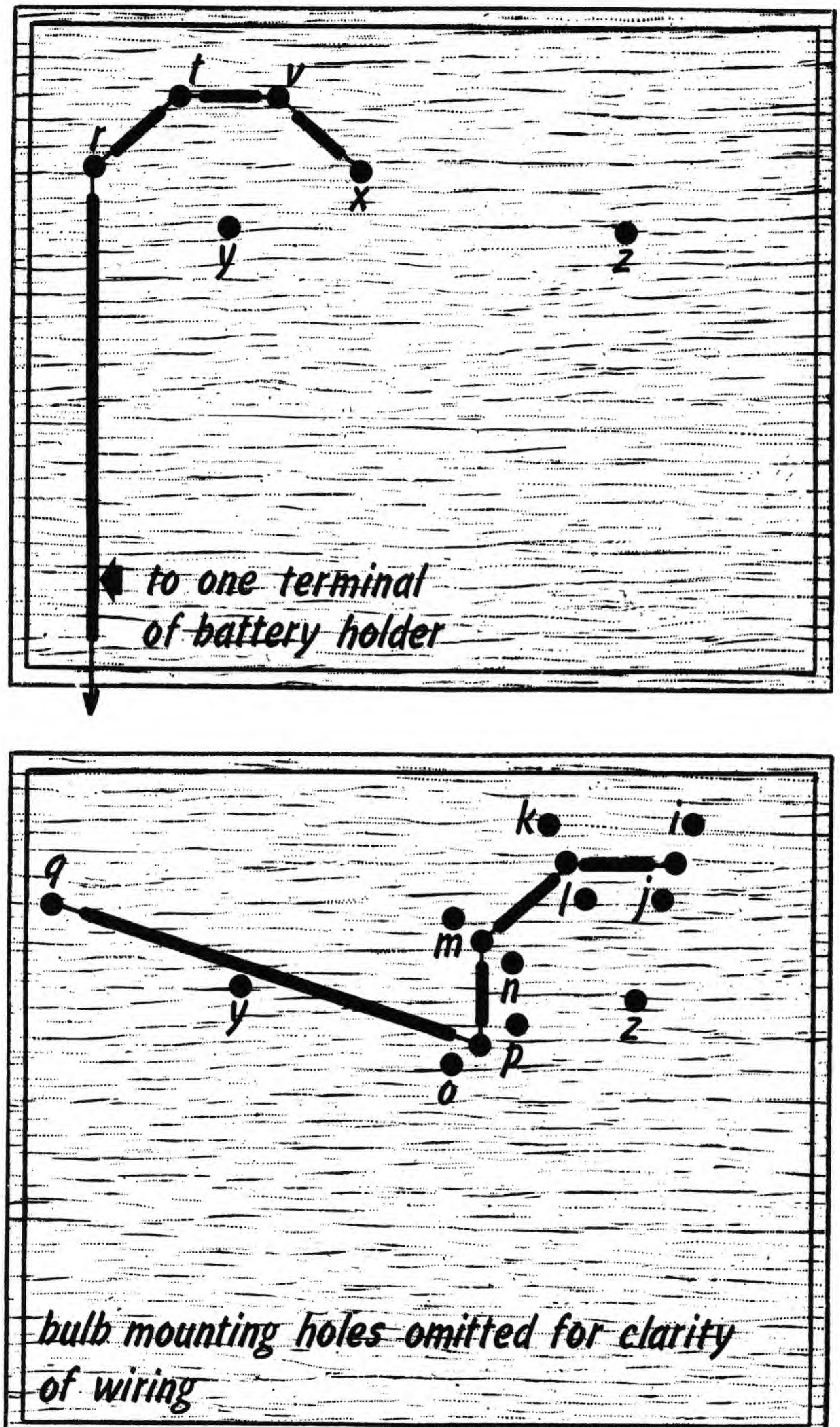


Fig. 39. Step-by-step wiring plans for switch Y (half scale).

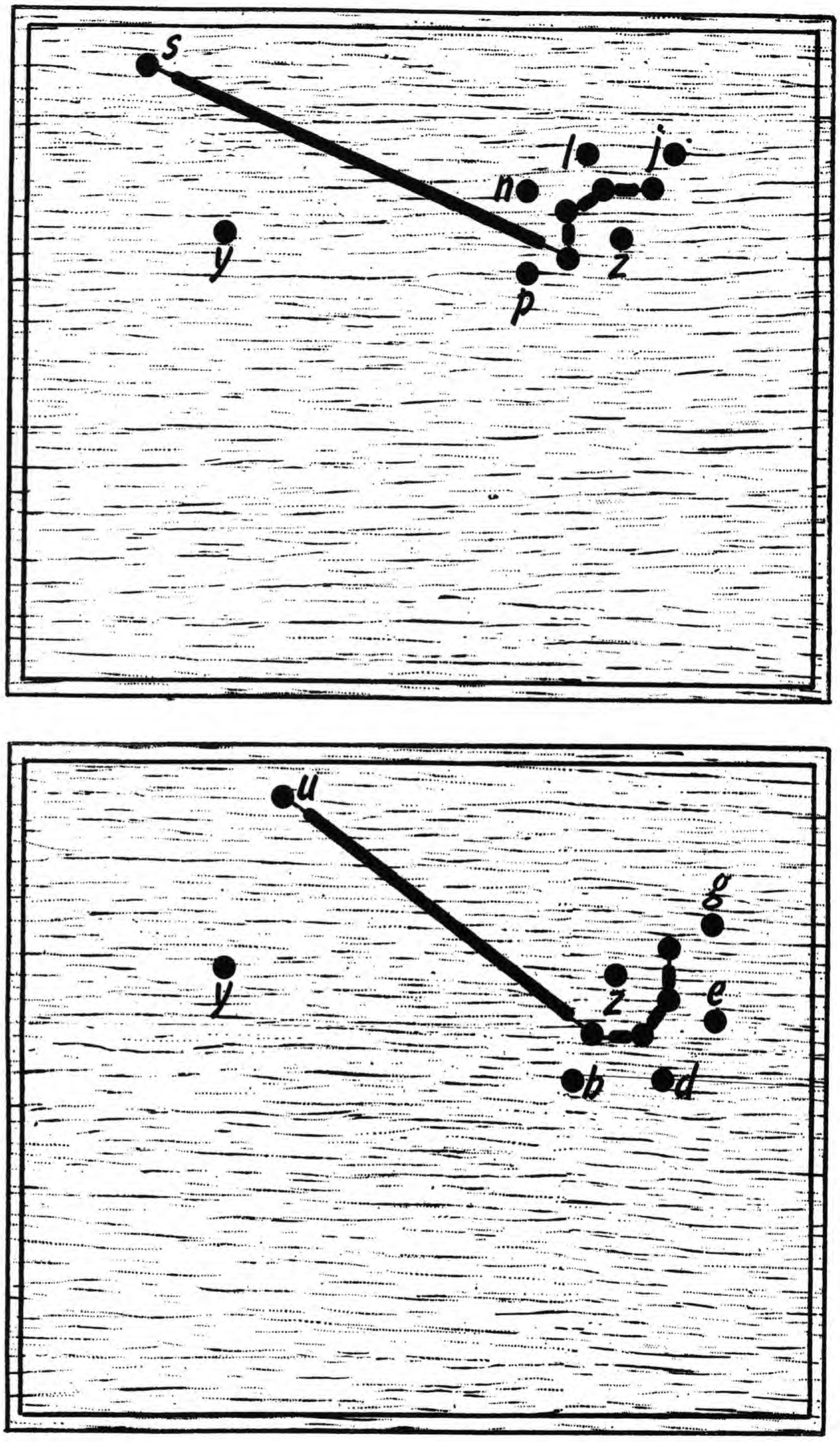


Fig. 40. Step-by-step wiring plans for switch Y continued.

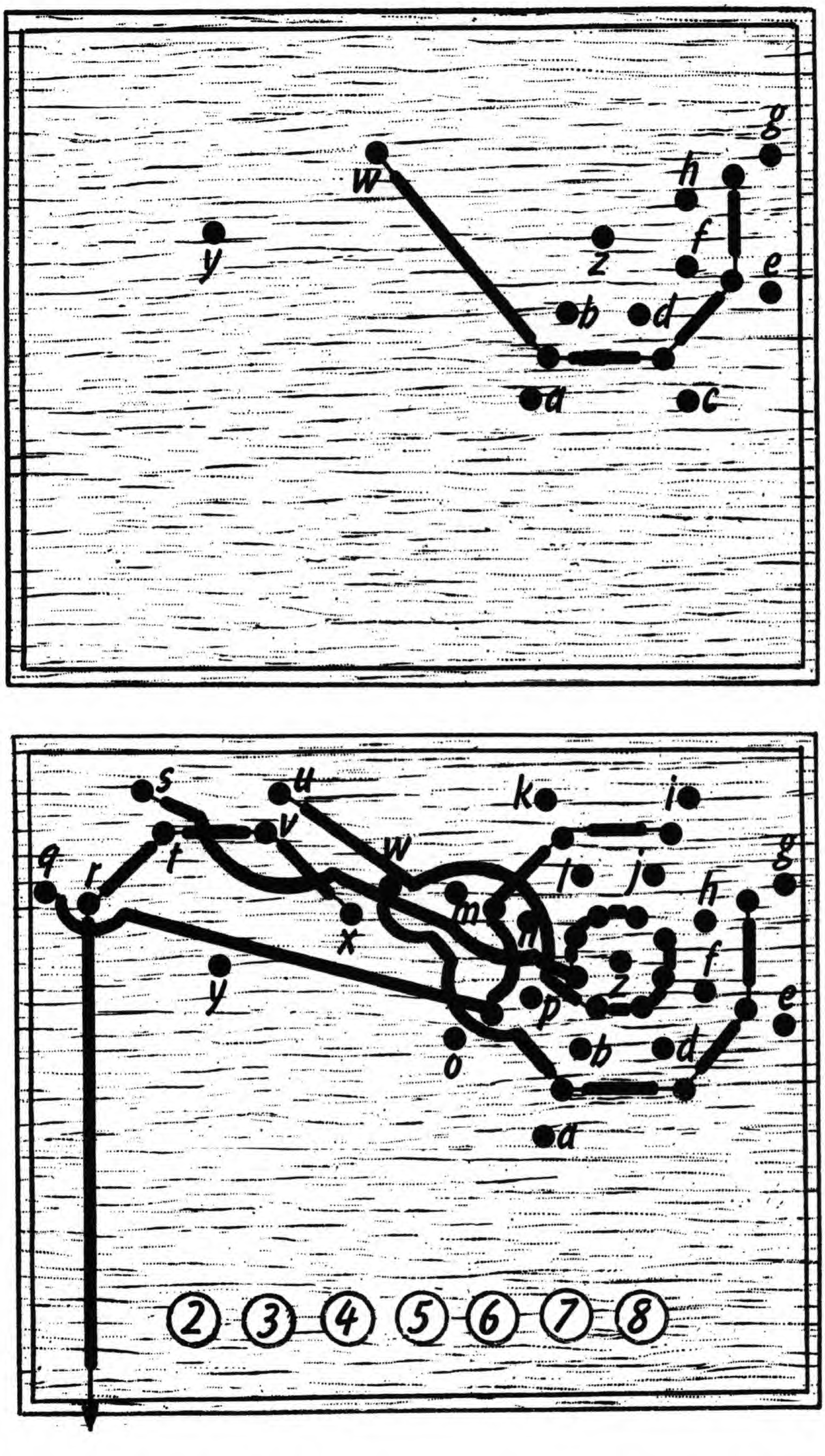


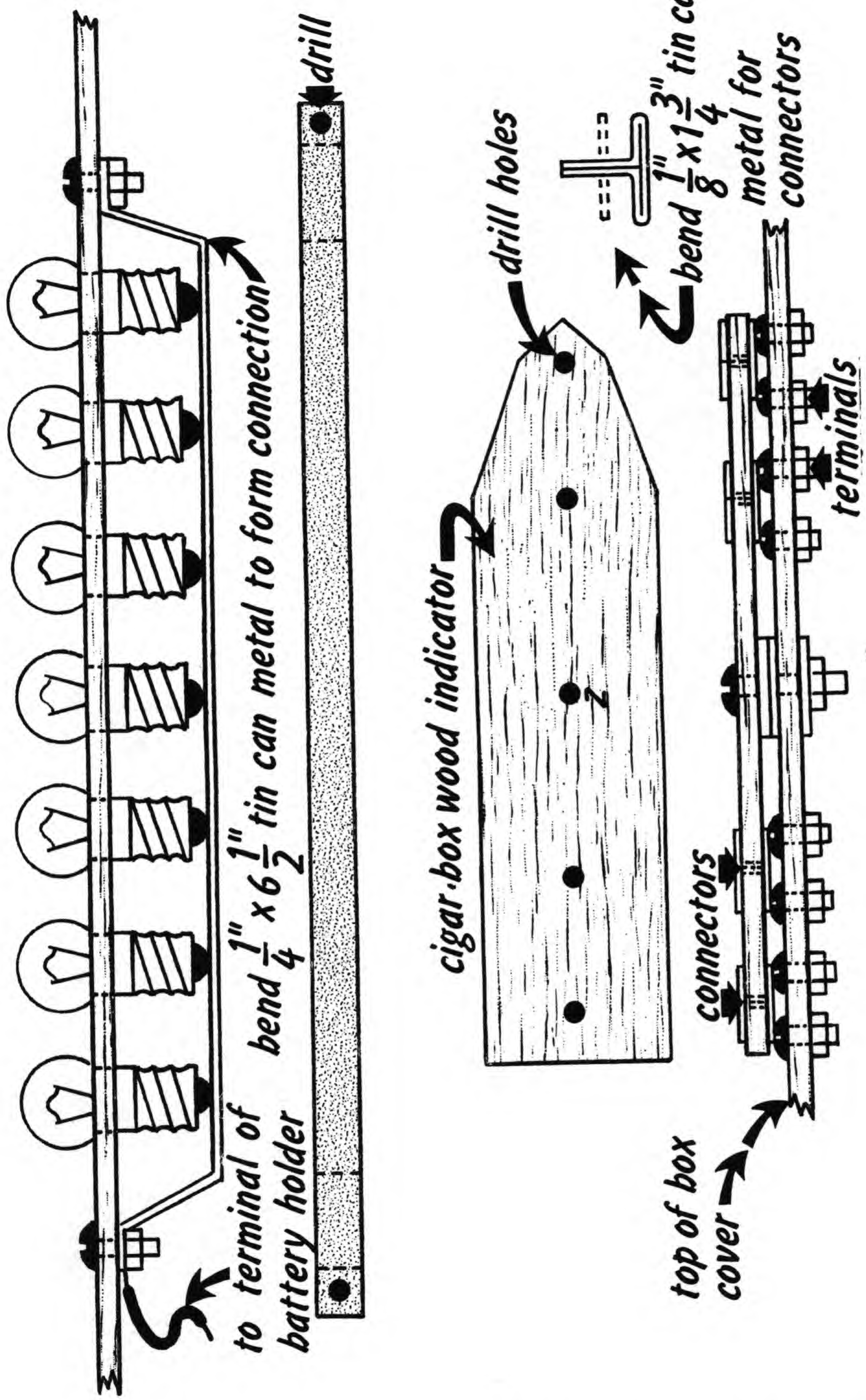
Fig. 41. Top: Step-by-step wiring plans for switch Y continued. Bottom: Completed wiring diagram for switch Y.

Check your wiring of switch Y against the diagram at the bottom of Fig. 41, and tighten the nuts or bend over the paper fasteners.

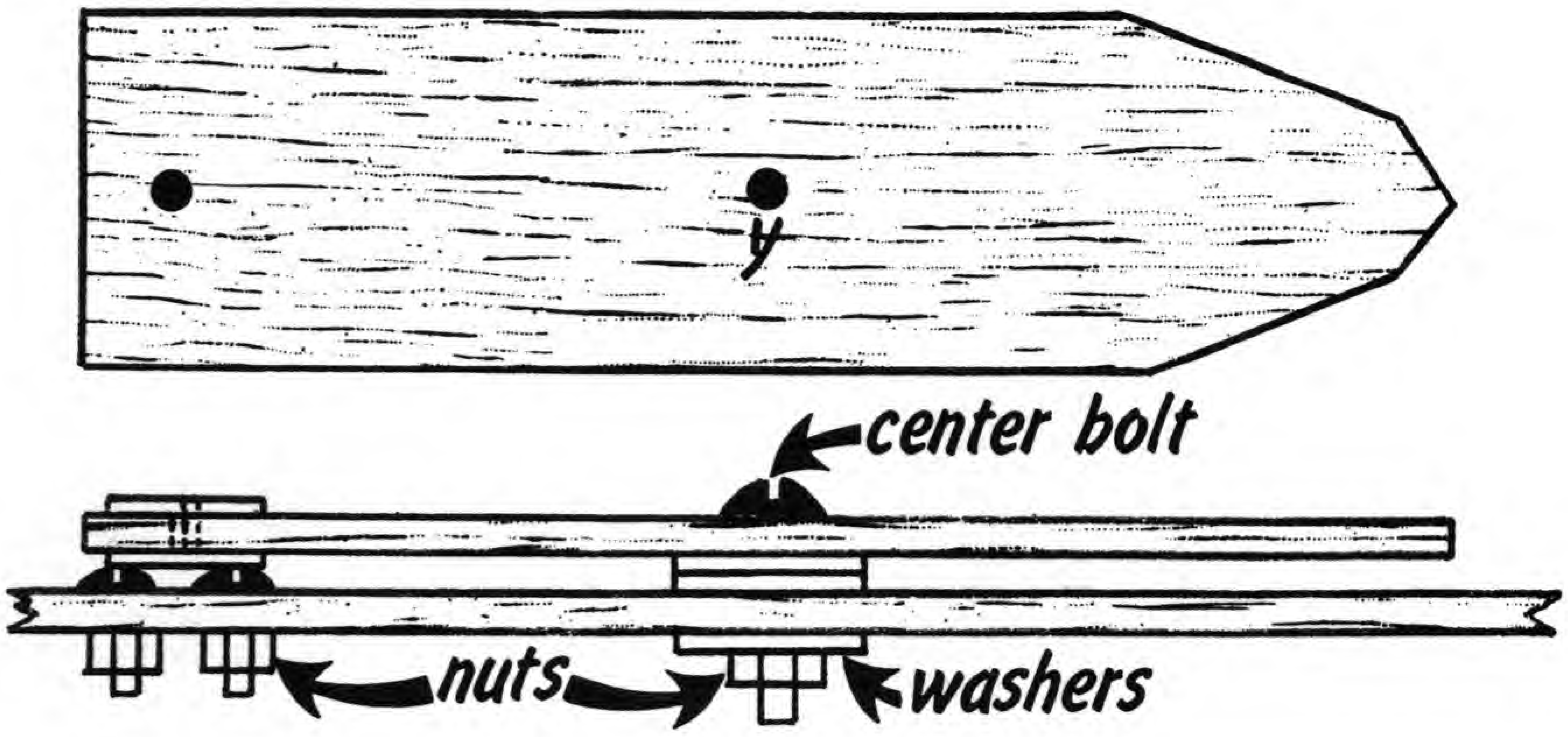
With the tin snips cut a strip of metal 1/2″ x 6 1/2″ out of the coffee can to be used as the connection for the base of the bulbs. Drill a 1/8″ hole in each end of the strip, bend as shown in Fig. 42, and fasten it to the box cover with paper fasteners or nuts and bolts. Make sure the strip touches the base of each bulb.

Now screw the double battery holder to the inside bottom of the box. Connect the wire from switch Y (terminal r) to one terminal of the battery holder. Next, cut a piece of wire long enough to reach from one end of the bulb-base connection to the other terminal of the battery holder, with enough extra length to allow for opening the cigar box. Strip the insulation from both ends of the wire, and attach one end to the right-hand screw in the bulb-base connection (see Fig. 42) and the other end to the second battery terminal.

Trace the full-size indicator patterns shown for switches Z and Y in Figs. 42 and 43, transfer the patterns to cigar-box or similar wood, and saw out. Drill 1/8″ holes in both switches as indicated in the patterns. Insert 1/2″-long rectangular-headed brass paper fasteners into underside of the connector-terminal holes (four in switch Z, one in switch Y). Strips of metal may be cut from a tin can and bent to shape as a substitute for the fasteners, but this will be a little



g. 42. *Top:* Cross section and top view of bulb-base connection. *Bottom:* Cross section of switch Z.



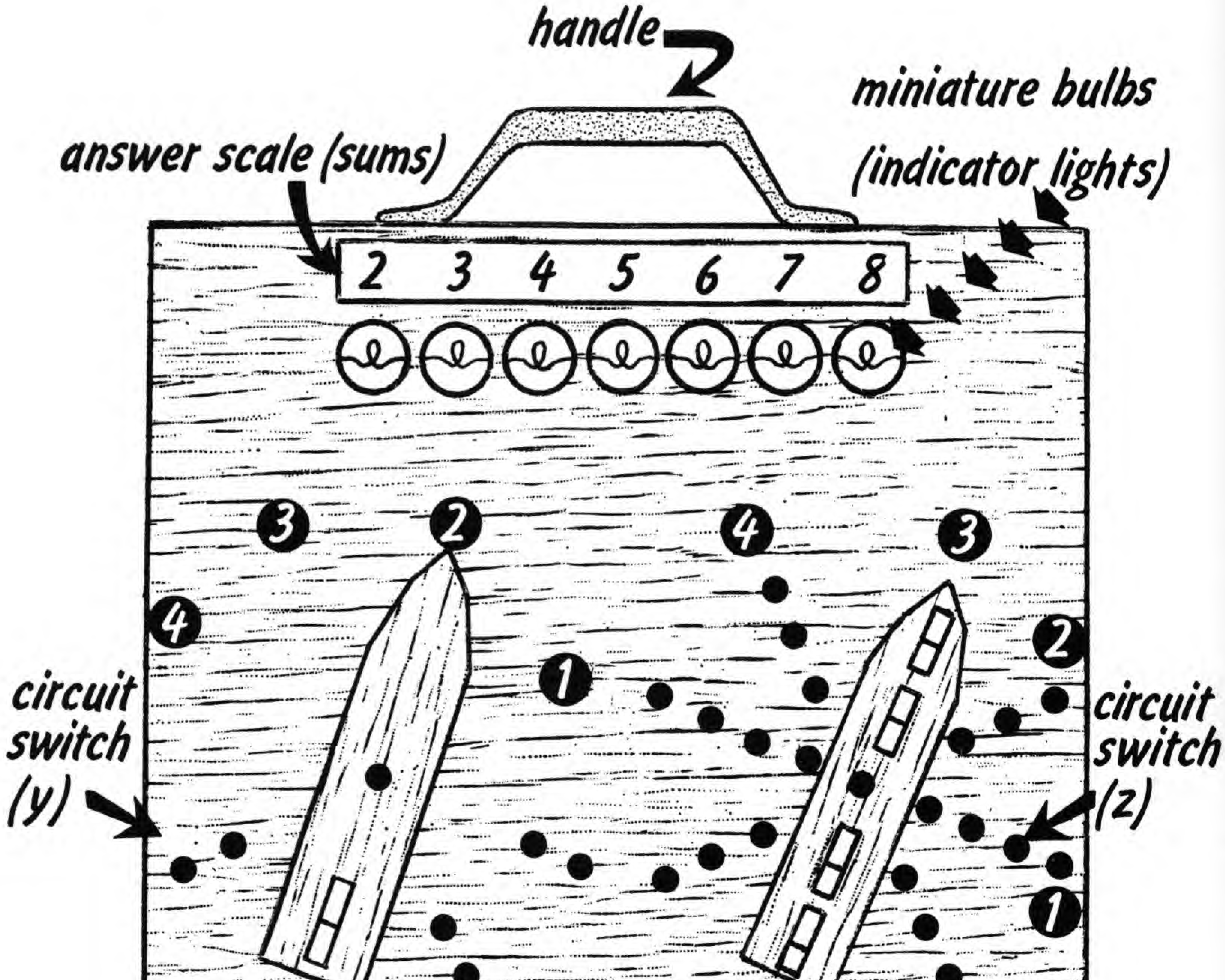


Fig. 43. Top: Cross section of switch Y. Bottom: Front view (half scale) of completed computer.

more difficult. Bend the ends of the fasteners firmly against the tops of the indicators.

Insert a 1/8″ x 3/4″ bolt through the middle hole in the top of each indicator, place two washers on each, screw into the Y and Z holes on the top of the cigar box, place another washer on each bolt, and tighten nuts to the underside of the box cover. The cross sections of switches Z and Y (Figs. 42 and 43) show how your switches should now look.

Cut a strip of white paper to fit along the top of the bulbs (or indicator lights), and glue it in place. Using pen and ink or decal numbers, put the numbers 2, 3, 4, 5, 6, 7, and 8 on the strip of paper above the bulbs, as shown at the bottom of Fig. 43. Cut circular pieces of paper to go above switches Y and Z and glue into place (see Fig. 43.) For now, put the numbers 1, 2, 3, and 4 on these disks of paper. Later you may want to experiment with other decimal or binary numbers. If you change the numbers above the switches, of course, you will also have to change those above the indicator lights.

To make the computer portable, screw a screen-door handle to the hinge side of the cigar box.

The front-view illustration in Fig. 43 shows how the finished computer should look.

Put the two cells into the battery holder and you are ready to compute. Make sure you put the cells in so the tip ends face in opposite directions. Set switch Y at one number and turn switch Z to the number you want to add to it. Due to

the way in which you have wired the circuits, the bulb above the sum of the two numbers you are adding will light up to give you the answer. Try some other addition problems with your own home-made digital computer. Though this is a simple device that as presently set up can only add numbers whose sum is up to eight, the principle on which it operates is similar to that in many of the electronic geniuses used today in business, industry, and government.

You can vary the addition problems the computer will solve by changing the numbers above the switches and bulbs. For instance, you can change the numbers on the switches to 5, 6, 7, and 8, and the numbers above the bulbs to 10, 11, 12, 13, 14, 15, and 16. Any combination of numbers can be used provided the numbers on the switches are *all the same,* are *in the same sequence,* and start with the lowest number on the right and go up to the highest number on the left.

If you wish, you can change the sequence of the numbers on the switches so that the lowest number is at the left and the highest is at the right, but you will then have to reverse the sequence of the numbers above the bulbs so that the lowest number is at the right and the highest at the left.

The numbers you use on the switches will determine the numbers to be used above the bulbs—these must run from the sum of the lowest two numbers on the switches up to the sum of the highest two numbers.

Try computing with binary numbers, substituting the binary equivalents shown in Fig. 11 for the decimal num-

bers on your computer. You can compute with the decimal and binary systems simultaneously by putting both numbers on the switches and one system above the indicator lights and the other below.

If this computer or the analogue computer you are about to construct should not work, check the following:

1. The two cells in the battery holder, to make sure they are producing current
2. The terminal connections—wires should be fastened securely to all terminals
3. The circuit, to make sure it is complete
4. The wires—there should be no broken wires (these sometimes break underneath the insulation), no bare wires crossing each other, and the wires at the terminal connections should be free of insulation

ANALOGUE COMPUTER

In 1879 William Thomson (Lord Kelvin), a British physicist and mathematician, drew up plans for a machine that could solve problems involving measurement. As we learned earlier in this book, a machine that solves problems through the use of measurement is termed an analogue computer.

But it was not until 1925 that Vannevar Bush, then a professor at the Massachusetts Institute of Technology, drew up the plans for and set about constructing the first analogue computer that was actually put into operation. The computer was completed and put into use five years later.

Let's construct, now, a simple version of an analogue computer. The basis for the computer you are about to build is the potentiometer. A potentiometer is an instrument for measuring the force of electricity in terms of volts. For our computer, scales have been worked out whereby one volt of electricity is equal to the number one. Working out such a scale is the basic problem in the construction of any analogue computer.

To build the computer, secure the following:

MATERIALS

Wooden cigar box, approximately 7″ x 8 1/2″ or larger

Typing paper

Fine pen and India ink

One 10-ohm potentiometer

- One 100-ohm potentiometer
- One 1,000-ohm potentiometer
- 3 indicator knobs to fit the shafts of the potentiometers
- 6 hex nuts to fit potentiometer shafts
- Insulated wire
- Small knife switch
- 0–1 microampere dc milliammeter
- Screen-door handle
- Double model airplane battery holder
- Two 1 1/2 volt flashlight cells, size D
- Model airplane cement for wood
- (If items such as the potentiometers, the knobs, and the meter are not available at your local electrical or electronic store, order them from one of the companies listed at the end of the book.)

TOOLS

- Hand or electric drill expansion bit, 3/8″ bit, 1/8″ bit (or large nail and hammer)
- Needle-nosed pliers with side cutters
- Electric soldering gun
- Small screwdriver
- Hacksaw
- File or emery cloth
- Ruler

Measure off the placement of the holes to be drilled in the top of the cigar box, following the measurements given in Fig. 44. Drill the holes, using the expansion bit for the large hole and the 3/8″ bit for the three smaller holes.

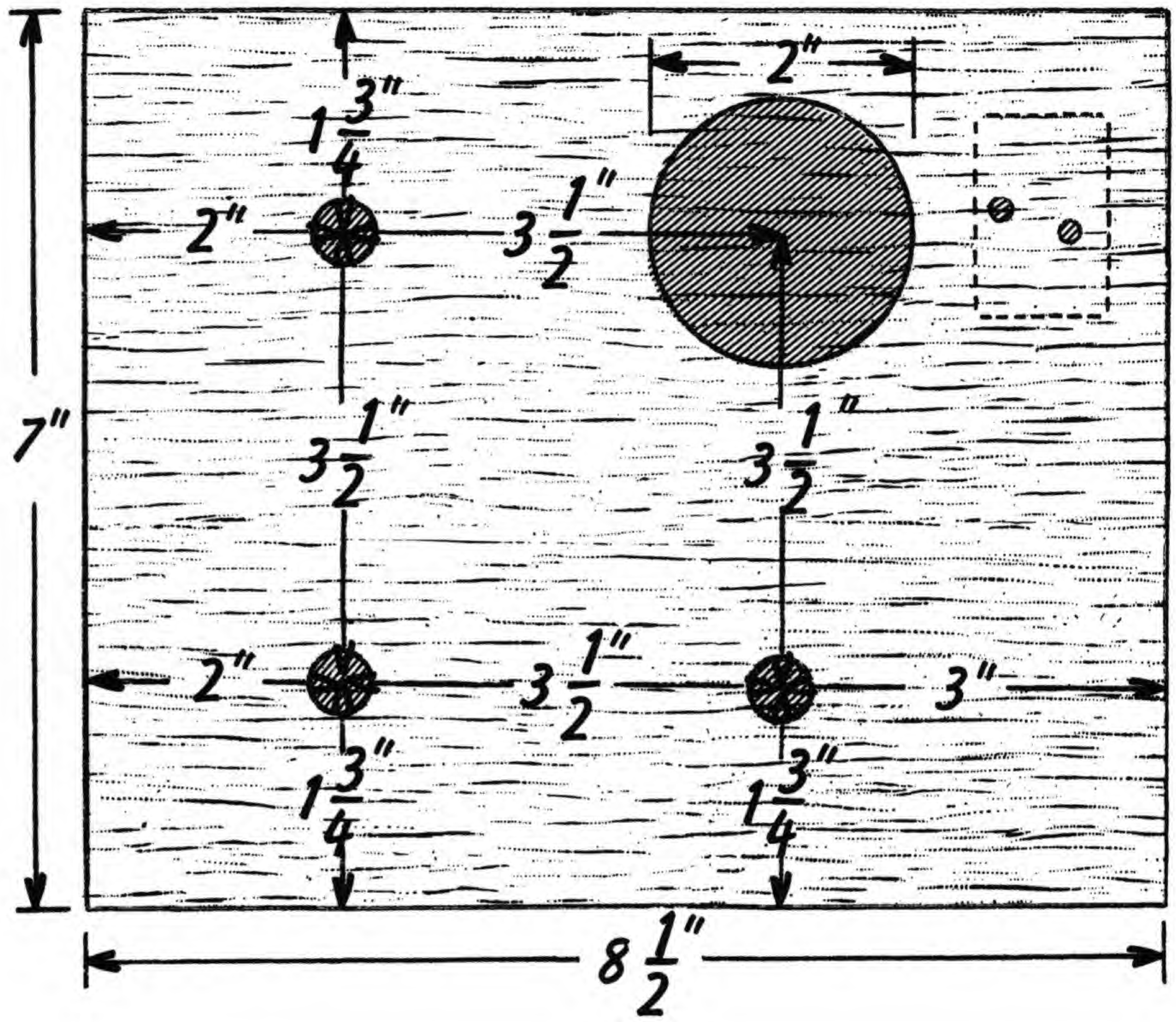


Fig. 44. Placement of holes in top of cigar box.

Lay thin typing paper over the calibrated scales shown in Fig. 45 and carefully trace them. Make two copies of the top scale and one copy of the bottom scale. Using a fine-pointed pen and a ruler, go over the lines with India ink. Write in the numbers or transfer decal numbers to the scales. Cut out the scales and the center holes shown by the shaded

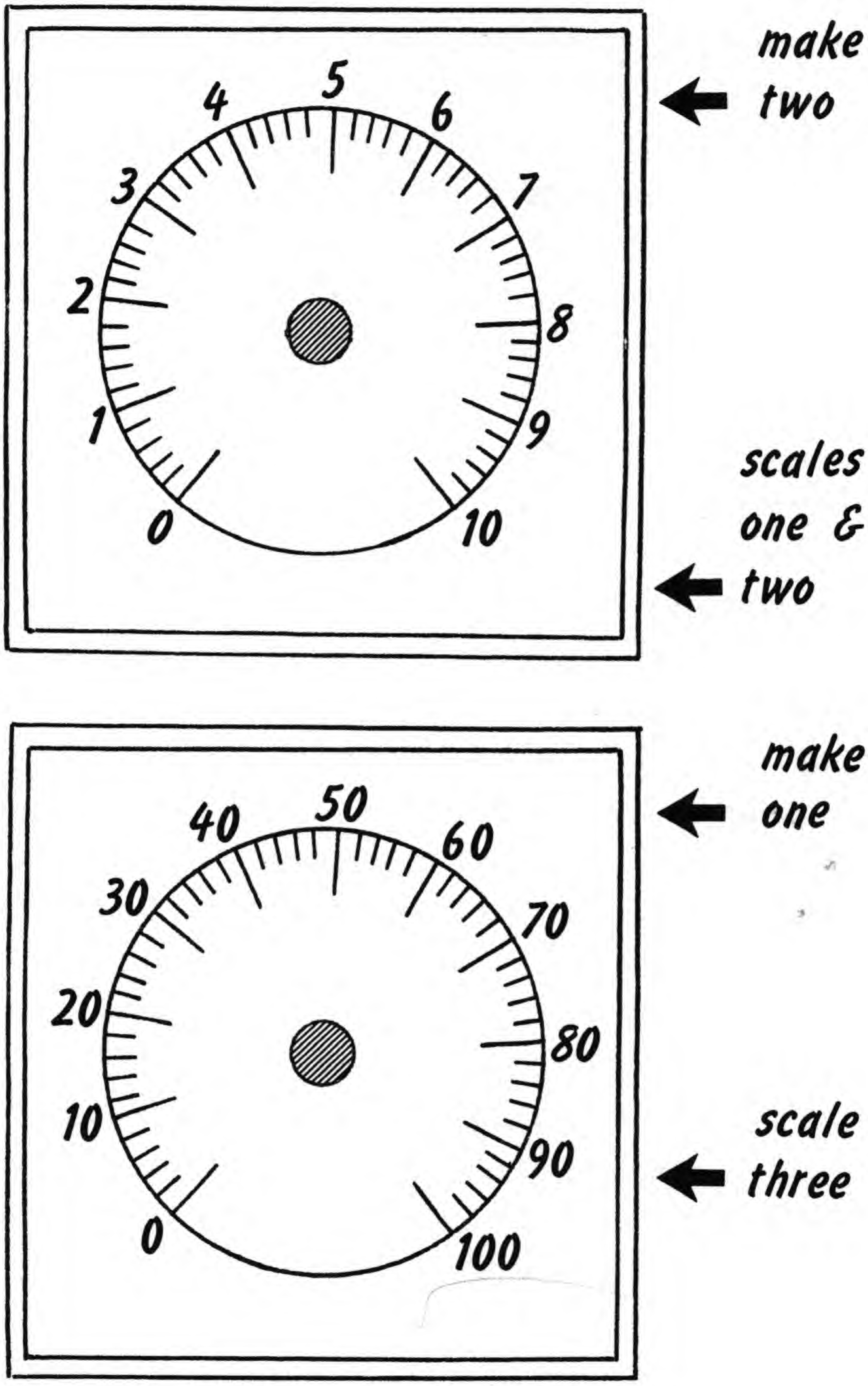


Fig. 45. Calibrated scales (full scale).

areas in Fig. 45. Glue the backs of the scales and place them on the top of the cigar box, centering them over the proper holes: scales one and two are glued over the holes in the left side of the box and scale three over the hole in the lower right-hand side.

Hacksaw the three potentiometer shafts to a length of 1/2″. It is best to clamp the shafts to a workbench or secure them in a vise when sawing. Screw a hexagonal nut onto each of the potentiometer shafts. Now, carefully slip the potentiometer shafts through the holes from the underside of the cigar-box cover, putting the 10-ohm potentiometer in the upper left hole, the 100-ohm in the hole at the lower left, and the 1,000-ohm in the hole at the lower right. Check placement of the potentiometers with the drawing at the top of Fig. 47, which shows their positions from the underside of the box lid. Put the lock washers that come with the potentiometers onto the shafts. Screw a hexagonal nut onto each shaft and carefully tighten it (see mounting detail in Fig. 46). Unloosen the set screws in the ends of the indicator knobs, put the knobs on the shafts, and tighten the set screws.

Now install the milliammeter. The meter has a brass clip attached to the back with two brass nuts. Remove the nuts, insert the meter through the topside of the cover, put the clip back into place, and tighten the nuts securely against the clip.

Refer now to the top of Fig. 47. Here each of the potentiometer terminals is numbered to make it easier for you to

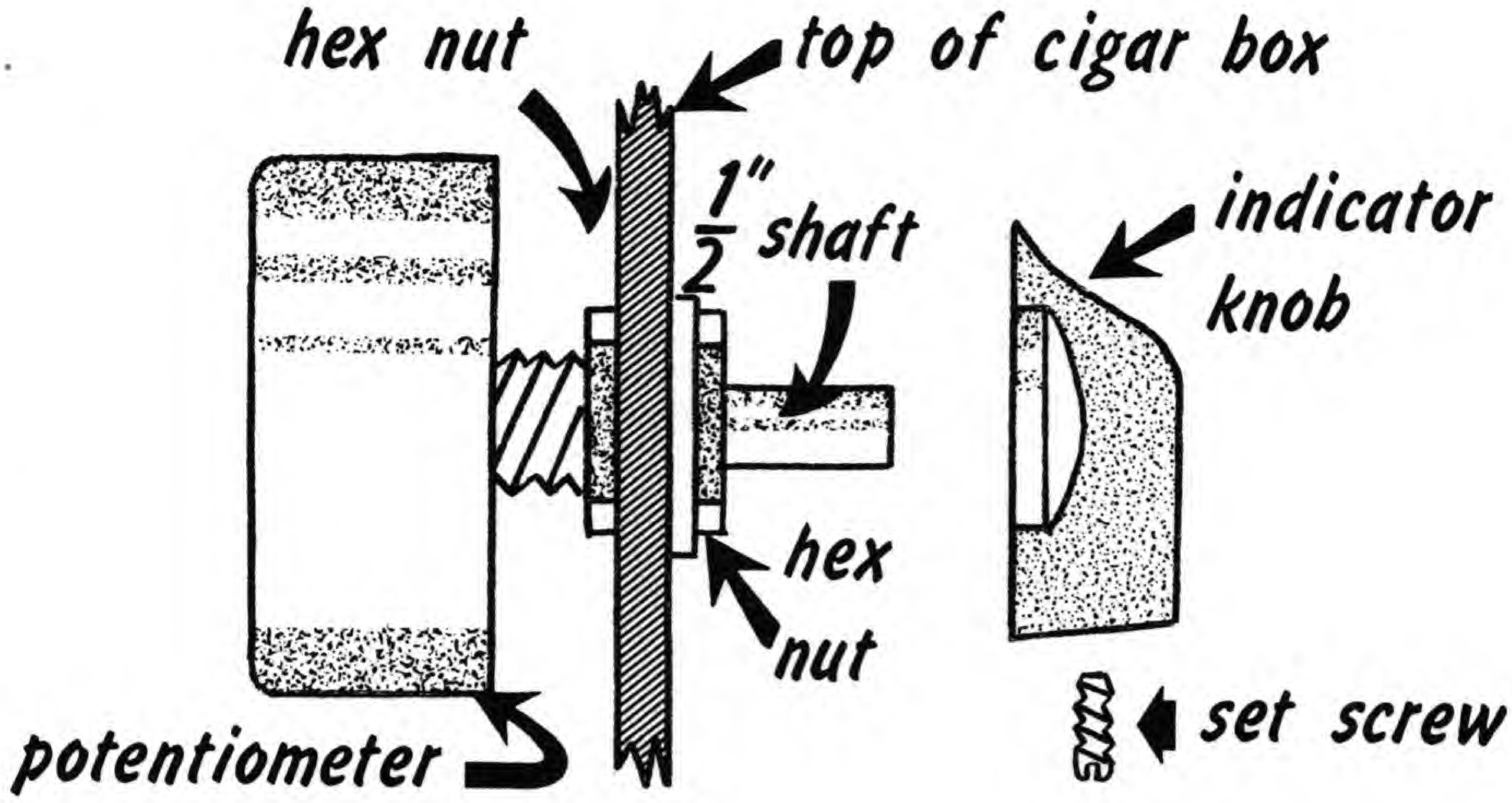


Fig. 46. Mounting detail (full scale).

follow the step-by-step wiring plans for the computer. Study the wiring diagrams before proceeding.

The terminal connecting wires should be cut 1 1/2″ longer than the measurement between the two terminals to be connected. Remove about 3/4″ of insulation from each end of all the wires.

Start wiring the computer. Connect terminal 3 of the 100-ohm potentiometer to terminal 6 of the 1,000-ohm potentiometer. Connect terminal 5 of the 1,000-ohm to terminal 10 of the meter. Check the wiring with the bottom drawing in Fig. 47. (All the wiring plans given in Figs. 47, 48, and 49 show the underside view of the cigar-box lid.)

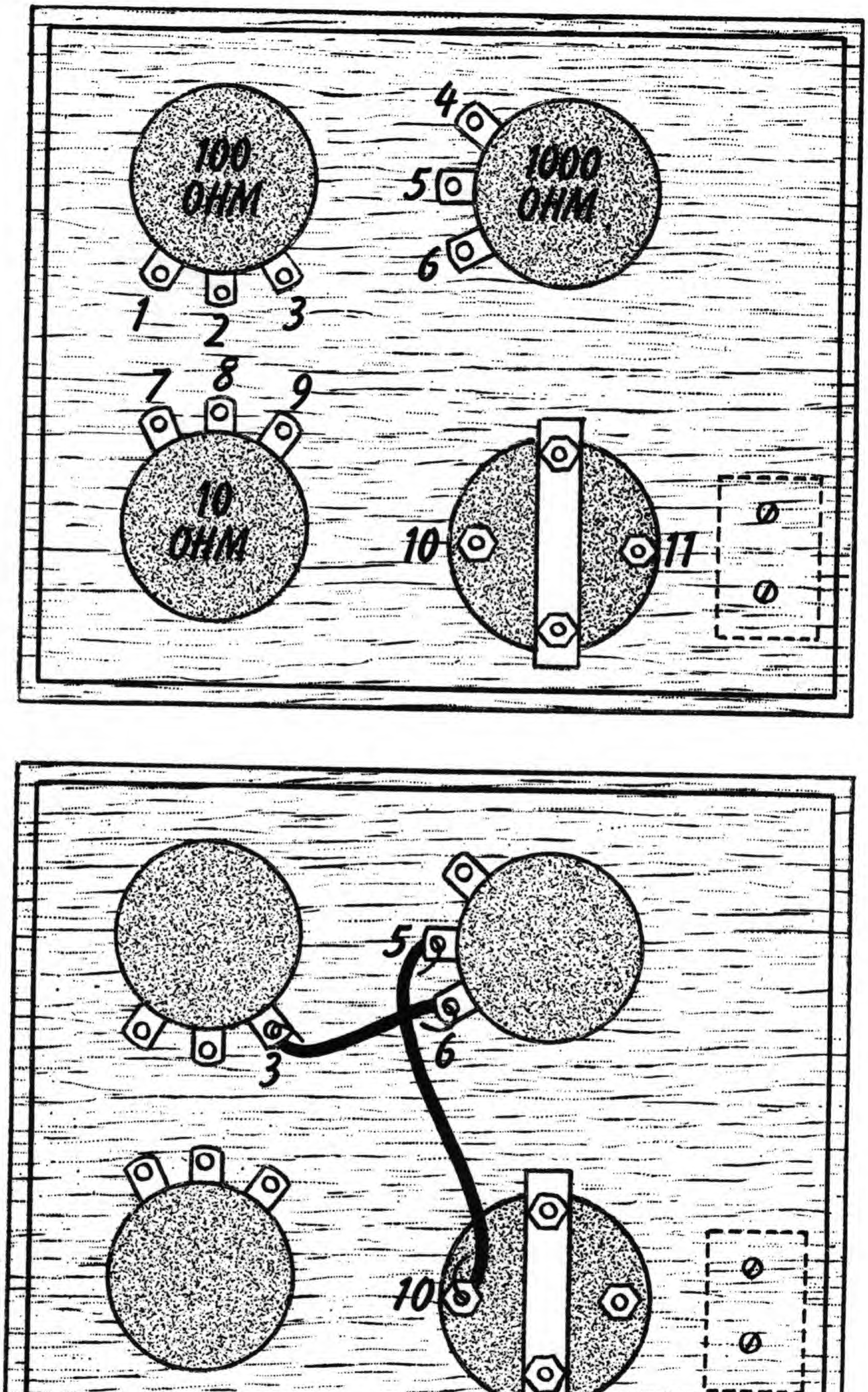


Fig. 47. Step-by-step wiring plans from underside of cigar-box cover (half scale).

Connect terminal 2 of the 100 ohm to terminal 11 of the meter and terminal 4 of the 1,000 ohm to terminal 9 of the 10 ohm. Check these connections with the top drawing in Fig. 48.

Now place the knife switch on the upper right-hand corner of the outside of the box cover. Mark the position of the two small holes at the left of the switch on the top of the cigar box. Drill 1/8″ holes through the box top at these points or hammer a large nail through the lid to make the holes. Screw the knife switch to the top of the box.

Connect another piece of wire to terminal 4 of the 1,000 ohm. The other end of this wire is connected to the plus terminal of the battery holder after it is installed. Wire terminal 6 of the 1,000 ohm to the lower terminal of the knife switch as seen from the underside of the cigar-box lid. (See lower diagram in Fig. 48 for the wiring of these two connections.)

Wire terminal 1 of the 100 ohm to terminal 8 of the 10 ohm and terminal 3 of the 100 ohm to terminal 7 of the 10 ohm (see top diagram in Fig. 49).

Screw the double model airplane battery holder to the bottom of the cigar box. Connect a wire to the upper terminal of the knife switch and attach the other end to the minus terminal of the battery holder. Now connect the other end of the wire from terminal 4 of the 1,000 ohm to the plus terminal of the battery holder. Check the completed wiring of the computer against the full wiring plan shown at the bottom of Fig. 49. Use a soldering gun to solder all the potentiometer connections.

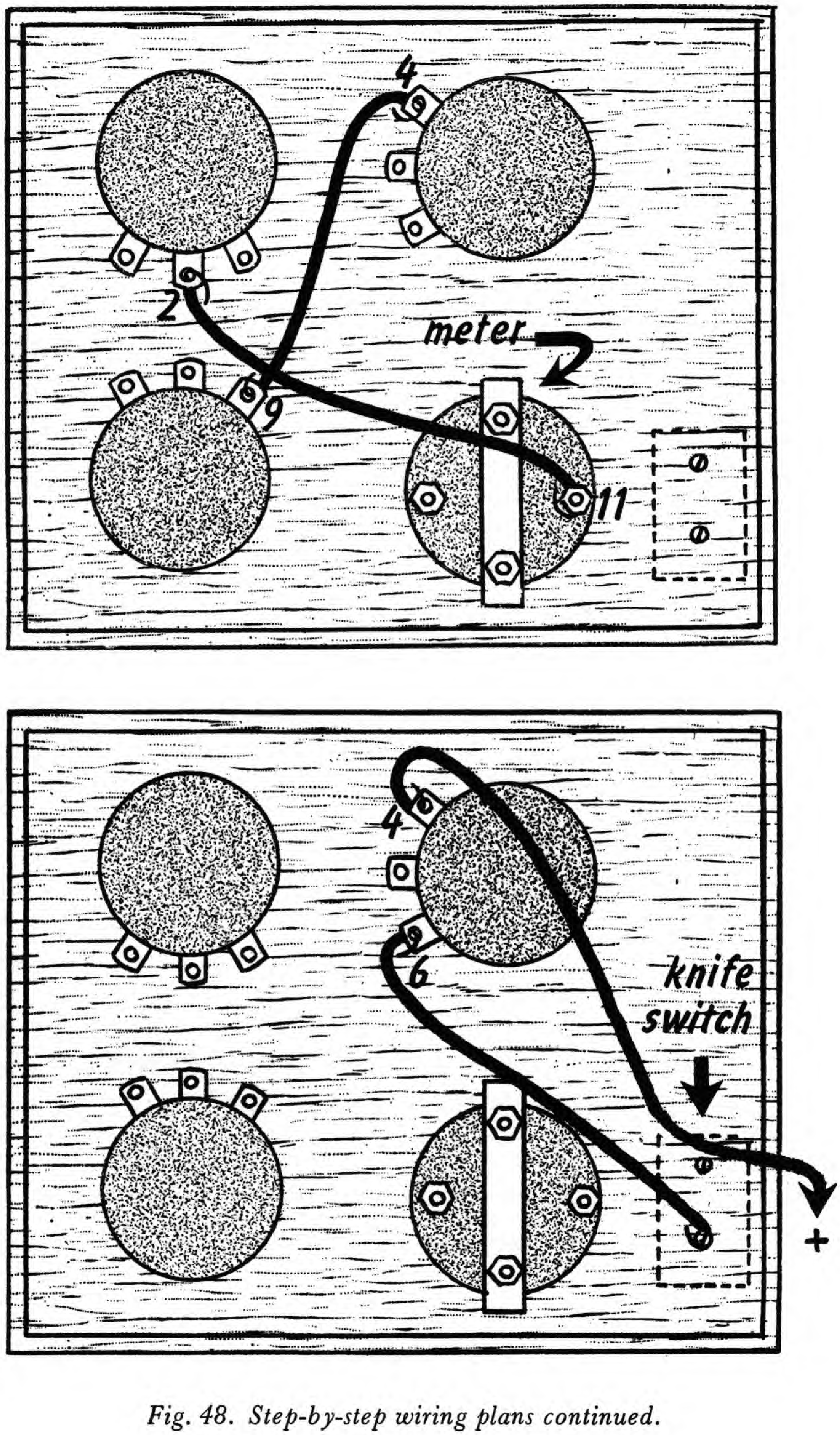


Fig. 48. Step-by-step wiring plans continued.

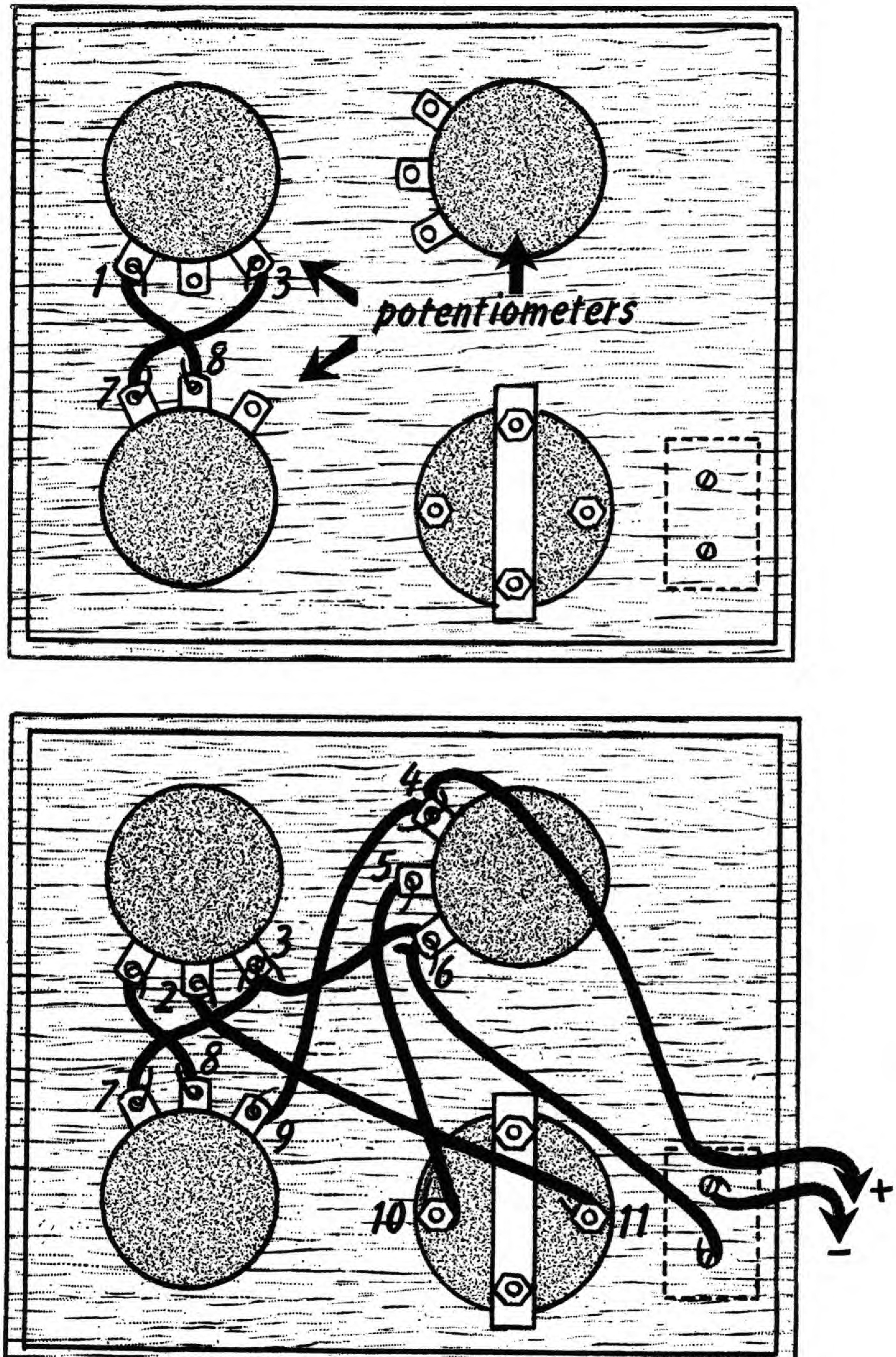


Fig. 49. Top: Step-by-step wiring plans continued. Bottom: Wiring plans completed.

Now turn each indicator knob as far as it will go to the right. Loosen the set screws and adjust the knobs so that each points accurately at the highest number on its scale. Tighten the screws.

Screw the screen-door handle to the top side of the computer to make it portable. The finished computer is shown in Fig. 50.

Insert the size D cells into the battery holder and the computer is ready to do multiplication and division problems. When multiplying, use the 100-ohm and the 10-ohm potentiometers as multiplier and multiplicand.

Close the knife switch to complete the circuit and set the indicator knobs of the 100-ohm and 10-ohm potentiometers at the two numbers you want to multiply. Move the knob on the 1,000-ohm potentiometer until the arrow on the milliammeter points to 0. The indicator knob on the 1,000-ohm potentiometer will then be pointing to the product of the two numbers you are multiplying.

A multiplication problem is illustrated in Fig. 50. Here 6 was multiplied by 5 and the answer is shown on the 1,000-ohm potentiometer to be 30. Practice other multiplication problems with the analogue computer.

To do division problems, use the 1,000-ohm potentiometer as the dividend, and the 10-ohm potentiometer to find the answer. (Fig. 50 can be used to illustrate a division problem also.) The knob on the 1,000-ohm potentiometer indicates the dividend 30 and the divisor 6 is shown on the 100-

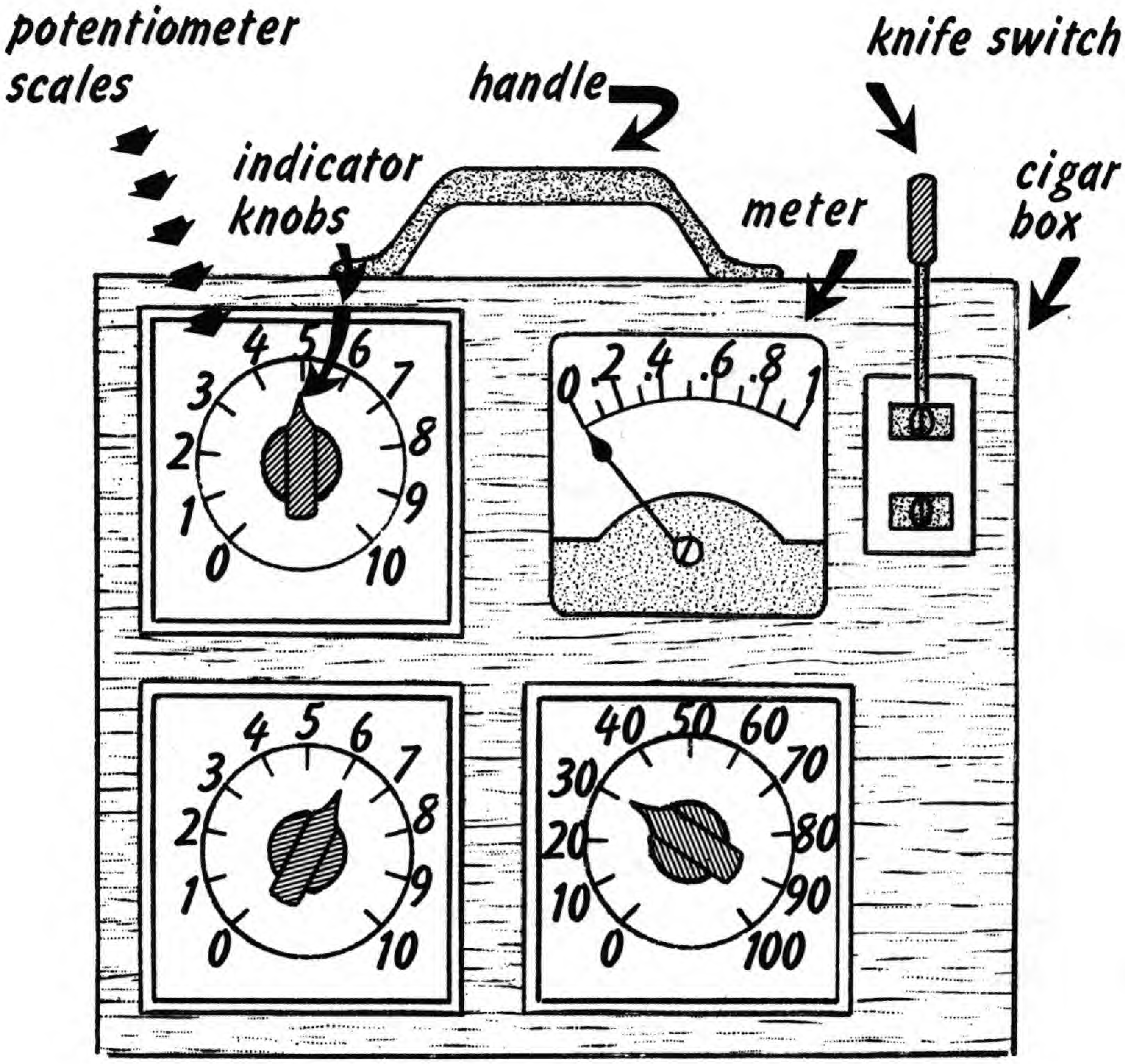


Fig. 50. Front view (half scale) of completed computer.

ohm potentiometer. Turn the 10-ohm potentiometer knob until the milliammeter reads 0 and the 10-ohm indicator will be pointing to the answer, 5.

Try more multiplication and division problems on the computer until you get answers quickly and accurately. If your answers do not seem to be precisely correct, remember that an analogue computer is usually slightly less accurate than most digital computers, which simply count numbers and do not relate basically dissimilar things. However, there is an adjustment that can be made on the computer that will make its readings more accurate. On the front of the milliammeter there is an adjustment screw. Set a problem and the known answer on the scales. Now turn the adjustment screw until the meter reads exactly 0.

Because of voltage loss due to battery deterioration, you will also have to readjust the meter just before the batteries go dead.

When you are not using the computer, be sure to open the knife switch so as to break the circuit and not drain the batteries.

Glossary

Analogue computer—A machine that operates on the basis of electrical analogues.

Binary number system—A system in which only two symbols, 1 and 0, are used to represent all decimal numbers.

Calculations—The act or process of solving or estimating an answer by mathematical methods.

Calculator—A machine, such as an adding machine or slide rule, that produces the result of only a *single* arithmetic operation.

Circuit—The complete path along which electricity flows.

Computer—A machine which solves a *complete* mathematical problem.

Control—The unit within an electronic computer that directs the sequence of operations in the computer.

Digital computer—A machine that produces mathematical answers by counting quantities and is usually limited to performing one of the four arithmetic operations of addition, subtraction, multiplication, or division at a time.

Electron gun—The part of the electron tube from which electrons are shot in a beam onto a screen.

Electronics—The experimentation with and application of the electron theory to radio, television, calculators, and computers.

Input—The unit within the computer into which information—in the form of manually operated switches, magnetic tapes, paper tapes, or punched cards—is fed.

Logarithms—A quantity or power, usually a number, placed above and at the right of a number or letter in mathematical calculations which tells how many times the number or letter is to be multiplied by itself.

Magnetic core—A type of storage device within a computer that is composed of ferro-magnetic rings through which current-carrying wires are threaded.

Magnetic tape—Another storage device within a computer that consists of a 1/2″-wide plastic or metal tape divided into vertical and horizontal tracks which are coated with material that accepts and retains magnetism.

Memory device—An electronic device used to file information in the storage unit of a computer.

Number system—Symbols or groups of symbols which represent graphically an arithmetical sum.

Odometer—A wheeled instrument used to measure distance.

Output—The unit in the computer where the answer to a problem is recorded.

Processing unit—The unit within a computer where the calculations are done.

Quantitative—The measurement of quantity.

Slide rule—An instrument made of sliding rulers used to calculate arithmetical answers.

Storage unit—The part of the computer where information is filed until it is needed for other operations.

Symbols—Signs, such as numbers or letters, used to represent quantities.

Where To Obtain Materials for Further Experiments

Materials for further explorations into the field of calculators and computers can be obtained from your local electrical or electronic shop or hobby store or from the following list of mail-order houses that will send catalogues free upon request. These houses can also supply you with the materials needed for the experimental devices in this book, should you have any difficulty obtaining them locally.

ABACUS SUPPLIES

Edmund Scientific Co., Barrington, New Jersey (abacus kit, packages of beads, and instruction books on the use of the abacus).

COMPUTER KITS (*under $20.00*)

Berkeley Enterprises, Inc., 815 Washington St., R 183, Newtonville 60, Mass. (Brainiac electric brain).

Oliver Garfield Co., Inc., 108 E. 16th St., New York 3, New York (Geniac electrical computers).

COMPUTER KITS (*over $35.00*)

Heath Co., Benton Harbor 10, Michigan (distributors of an educational electronic analogue computer).

ELECTRONIC SUPPLIES

Allied Radio Corp., Dept. 135-D9, 100 N. Western Ave., Chicago, Illinois.

Heathkit Company, Benton Harbor 10, Michigan.

Lafayette Radio, Dept. 1D-9, P.O. Box 511, Jamaica 31, New York.

Radio Shack Corp., Dept. 4B, 730 Commonwealth Ave., Boston 17, Mass.

About the Author

Raymond G. Kenyon was born in Gloversville, New York, in 1922. He received his B. Ed. degree at the State University of New York in Oswego and his M. A. at New York University in New York City. He also attended the University of Buffalo and the Munson William Proctor Art Institute.

Mr. Kenyon has taught in the public schools of New York state from kindergarten through the twelfth grade and was principal of the Babylon, Long Island, elementary school. He is now a professor of education at the State University of New York at New Paltz. In addition to this, he has taught summer school at the University of West Virginia and been a curriculum consultant on science and mathematics in various parts of New York state. During World War II, he served in the Combat Engineers with the Third Army in Europe.

Mr. Kenyon's interest and experience in education has taken him into educational radio and television work as well. Recently he did a series of television programs on science for elementary school teachers over station

WPIX in New York City. He has also had published a series of science packets on such subjects as electricity, weather, rockets, atomic energy, jet propulsion, radar, television, and astronomy and has written articles on science and mathematics for The Instructor, The Peabody Journal of Education, *and other well-known educational journals. He lectures frequently before teacher and public groups and at educational conferences.*

The author and his wife and three children (identical girl twins and a boy) now live in New Paltz during the school year and at their home in Woodstock, New York, during the summer.

A former basketball and football player, Mr. Kenyon now enjoys tennis and swimming. His hobbies include sculpture, oil painting, silversmithing, copper enameling, origami, model building, and scientific experimentation. His sculpture and paintings have been exhibited at art galleries, and he won first prize in wood and aluminum sculpture at the Marvin House Exhibit in Jamestown, New York, and at the New York State Art Teachers' Show in Utica.

I CAN LEARN ABOUT CALCULATORS AND COMPUTERS *is Mr. Kenyon's first book.*

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